PROJECTS ■ THEORY ■ APPLICATIONS ■ CIRCUITS ■ TECHNOLOGY

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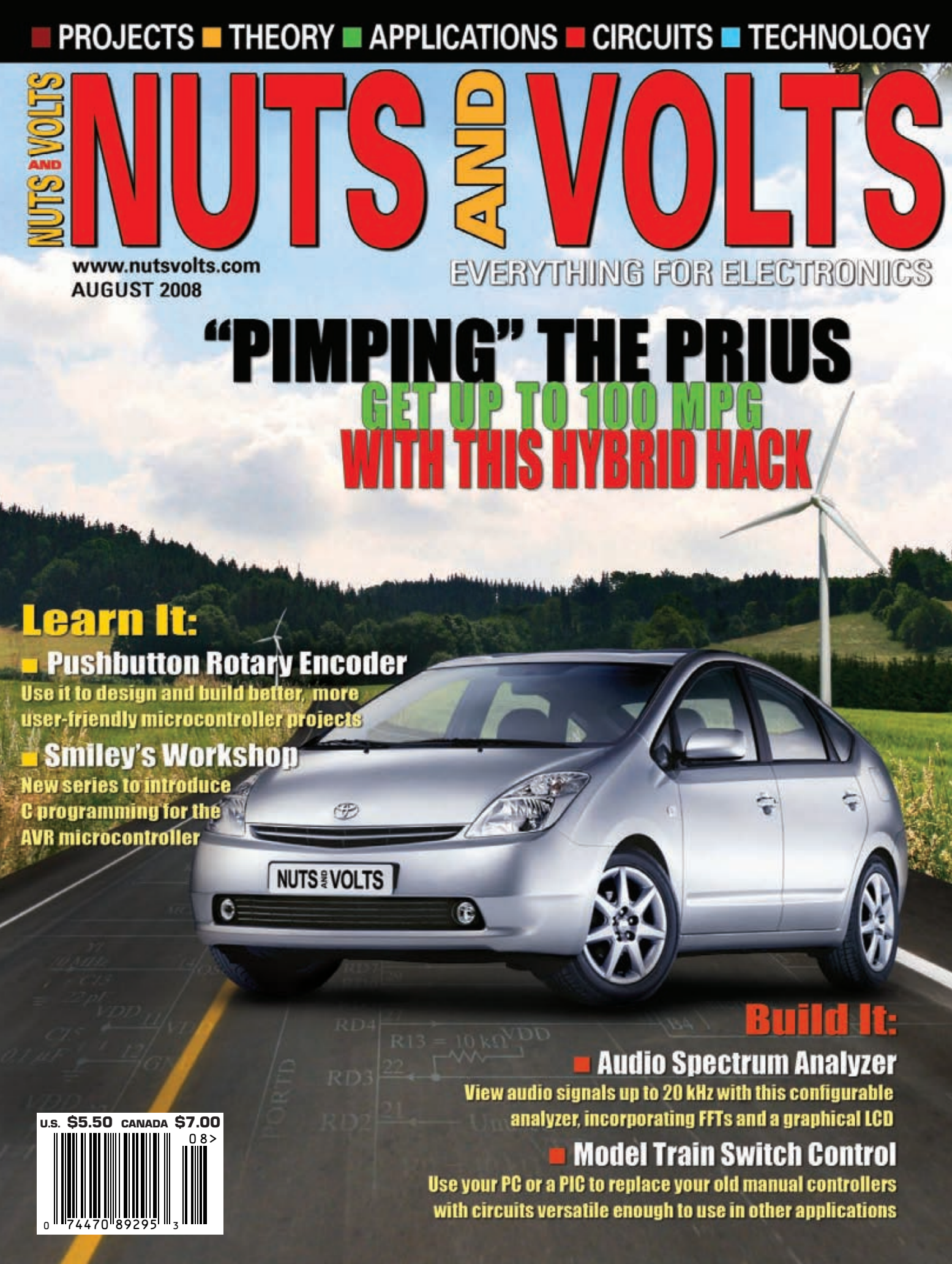

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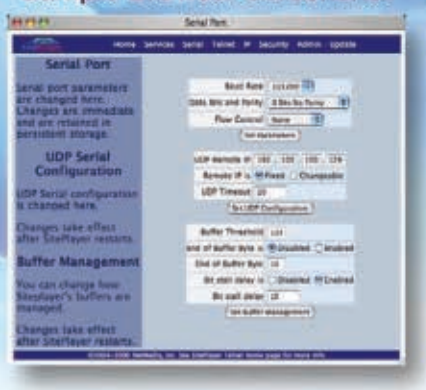

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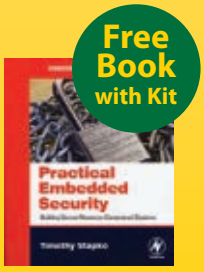

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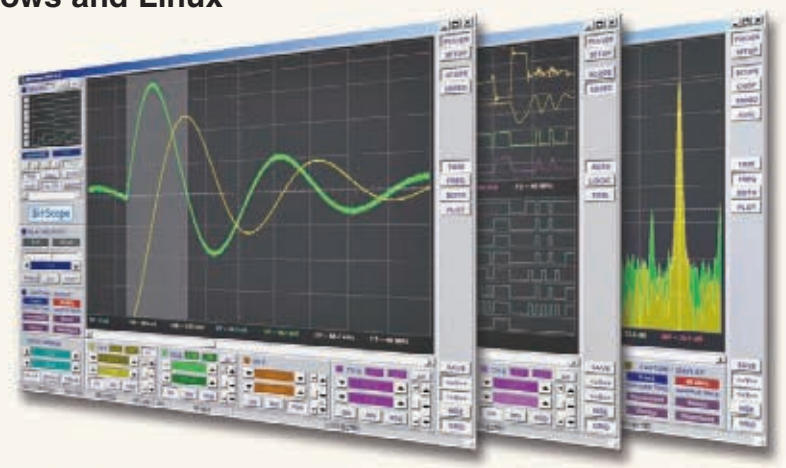

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Projects

38 MODEL TRAIN SWITCH CONTROL VIA PC OR PIC

Either version of this control system can easily replace your old manual controllers, plus the circuits are versatile enough to use in other applications.

■ *By Dan Gravatt*

●●●● Advanced Level

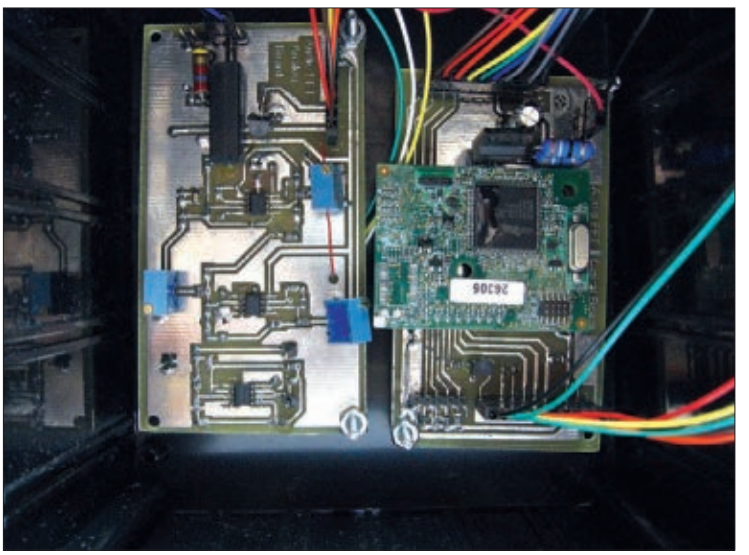
Page 38

44 AUDIO SPECTRUM ANALYZER

The device described here is a configurable audio spectrum analyzer incorporating FFTs and a graphical LCD. You'll also be able to vew audio signals up to approximately 20 kHz. (And who doesn't need that?)

■ *By Larry Cicchinelli*

●●●● Advanced Level



Page 44

Departments

08	DEVELOPING PERSPECTIVES	66	ELECTRO-NET
10	READER FEEDBACK	86	CLASSIFIEDS
34	NEW PRODUCTS	88	NV WEBSTORE
36	SHOWCASE	94	TECH FORUM
		97	AD INDEX

Be sure to check the Nuts & Volts website for downloads that go along with these projects.

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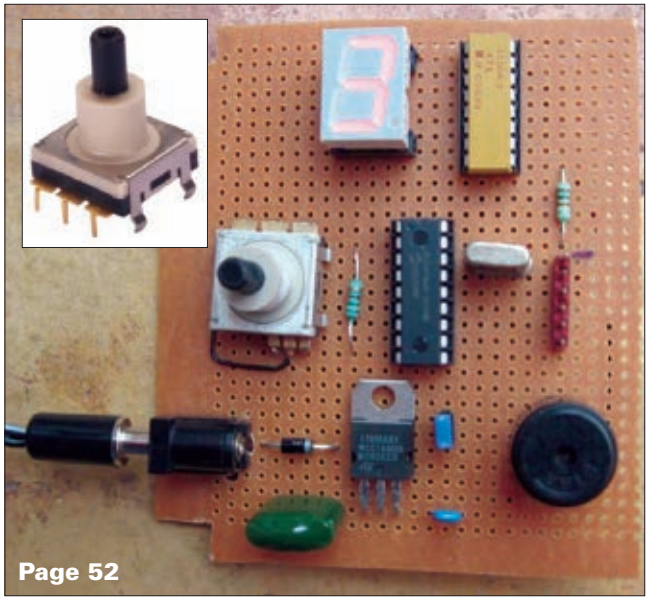

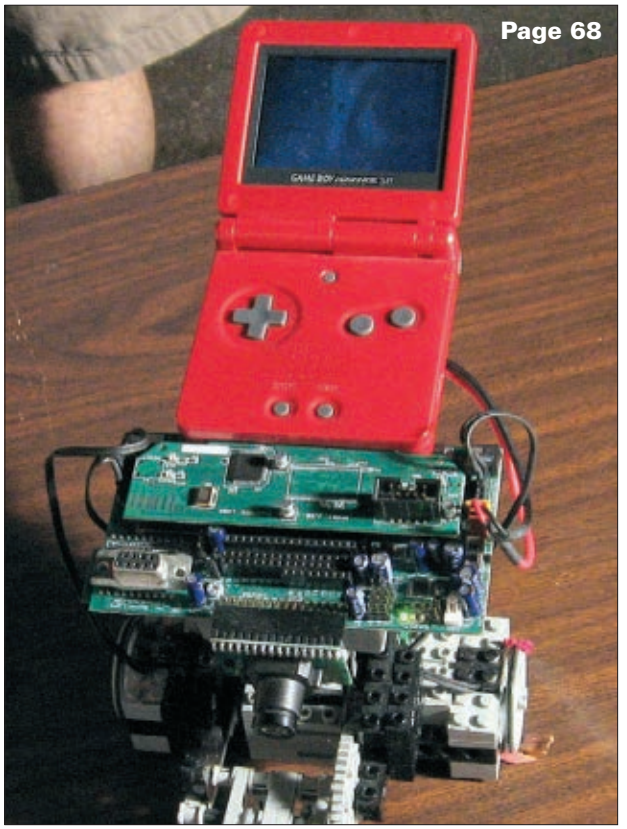

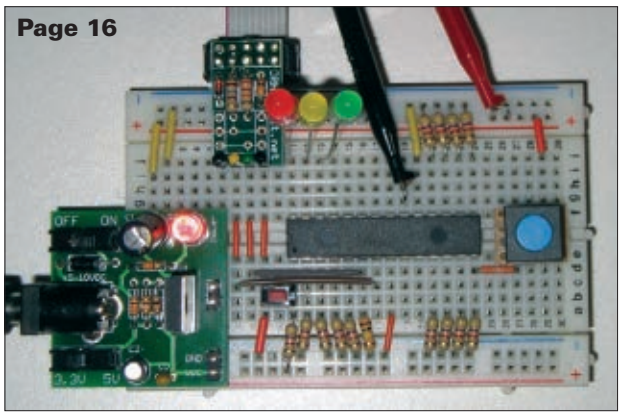

Features

52 HOW TO USE THE PUSHBUTTON ROTARY ENCODER
Learn how using a pushbutton rotary encoder can help you design and build better, more user-friendly microcontroller projects.
■ *By Jack Botner*

56 HACKING THE PRIUS WITH MATRIX MULTIMEDIA'S E-BLOCKS AND FLOWCODE
Read how this very satisfied customer used some ingenuity along with E-blocks and Flowcode, and got up to 100 mpg.
■ *By Jim Fell*

61 SMILEY'S WORKSHOP: AN AVR C PROGRAMMING SERIES
This new series of workshops will introduce C programming for the AVR microcontroller.
■ *By Joe Pardue*

Columns

12 TECHKNOWLEDGEY 2008
Events, Advances, and News
Topics covered include a flying saucer, a computer inside a pen, another win for the good guys, plus other interesting stuff.

16 PICAXE PRIMER
Sharpening Your Tools of Creativity
Getting started with the PICAXE-28X1 microcontroller.

26 Q&A
Reader Questions Answered Here
Fly zapper, vacuum tube circuit, solar tracker, more.

68 PERSONAL ROBOTICS
Understanding, Designing & Constructing Robots
DORKBOT: People doing weird things with electricity.

76 OPEN COMMUNICATION
The Latest in Networking and Wireless Technologies
Ten things you may not know about Bluetooth.

79 THE DESIGN CYCLE
Advanced Techniques for Design Engineers
Up the logic food chain.

by Bryan Bergeron, Editor

DEVELOPING PERSPECTIVES

Memristors — Rethinking the Fundamentals

Every electronics enthusiast and engineer is familiar with the fundamental passive circuit elements — resistors, capacitors, and inductors. With these elements, a source of power, and a few transistors, diodes, or other active elements, it's possible to create just about every electronics device imaginable. Or perhaps not. What if our perception of what's possible is limited by the nature of these basic elements? What could you create if you had additional elements to work with? Can you imagine a new element, and how it might be used in communications, computing, robotics, and entertainment?

In 1971, Leon Chau of UC Berkley did more than wishful thinking and postulated a fourth element: the memristor [1]. The theoretical device — which some engineers have termed the 'missing element' — could remember the changes in current passing through it by changing its resistance. What's remarkable about Chau's mathematical postulate is that this past May, researchers at HP Labs, Palo Alto, announced they had actually developed memristors. And, as expected, several patents assigned to HP dealing with memristors suddenly appeared on the USPTO website. Apparently, scientists at HP have been working with memristors for some time now.

According to Chau's publications, press releases from HP, and patent applications, a memristor behaves like a non-linear resistor with memory — a behavior due to hysteresis. Electrical hysteresis is commonly associated with ferromagnetic materials, as depicted by the double-s-shaped hysteresis loop. While hysteresis is often an annoyance in magnetic tape and hard drive circuitry, it has many practical applications in electronics. The use of a Schmitt trigger to eliminate contact bounce in switches is one practical application of hysteresis.

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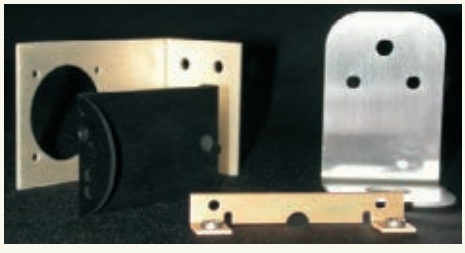

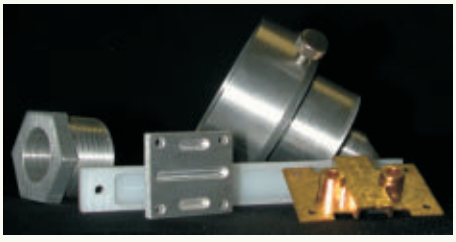

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According to patent applications, HP's memristor design is based on a sandwich of titanium dioxide films that loosely resembles the construction of a capacitor. However, unlike capacitors, one layer of titanium film is an insulator while the other layer is doped so that it is a conductor. Wires on either side of the sandwich are used to pass a charge through the film. Current through the film lowers the resistance of the film by a factor of 1,000. In this respect, the memristor seems a lot like an active device to me, but it's nonetheless classified as a passive circuit element.

Some of the first applications of memristors will likely be high-density, energy-efficient memory devices that compete with Flash memory devices. However, as with any new technology, it's difficult to predict what will come of the memristor. Because the memristor has qualities of both analog and digital circuitry, one application identified by HP is the development of memristor-based neural networks [2]. Perhaps memristors will make it possible to implement affordable, semi-autonomous robots with a semblance of intelligence.

If you're like me, you probably can't wait to order an assortment of memristors from Mouser or Jameco. However, we're not there yet. We'll probably have to be content with a SPICE simulation or other virtual experience for months, if not a year or more.

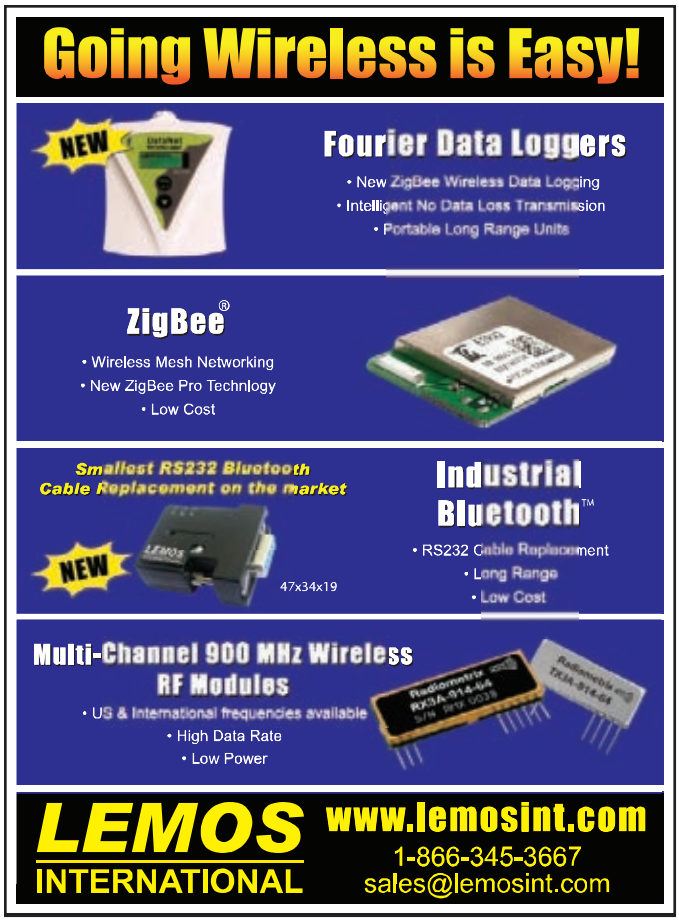
One of the unfortunate aspects of memristors — from the perspective of an electronics experimenter eager to create the first 'must have' device using memristors — is that just about every imaginable application is patented. Take a look at uspto.gov or **www.freepatentsonline.com**. One of the most straightforward patent applications — United States Patent 20080090337 — is for an electrically actuated switch. The application provides a good background on the mathematics and physics of a memristor. A second patent application — United States Patent 20080079029, 'Multi-terminal electrically actuated switch' — provides additional information, including specifics on materials and doping.

It's not likely that memristors will make time travel or anti-gravity possible. However, it's a new building block that will undoubtedly have myriad practical applications in areas ranging from computing and entertainment to automotive electronics. And you can be certain that *Nuts & Volts* will be featuring projects that illustrate the utility of the memristor — just as soon as I can get my hands on one. **NV**

REFERENCES

[1] Chua, L. Memristor — The missing circuit element. *IEEE Transactions on Circuits Theory*, Volume 18, Issue 5, Sep 1971 Page(s): 507 – 519.

[2] Johnson, RC. First proof of circuit theory's 'missing link?' *EETimes*. Monday, May 5, 2008. Page(s): 1-6.



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READY TO DIVE INTO PCB PRODUCTION

Thank you, thank you, thank you!

For some time now, I have been sitting on the fence thinking I need to figure out how to create my own PCBs using **expresspcb.com**. I have been reluctant to wade into those waters, however, because of my inexperience with this aspect of electronics. Just last week I recall thinking to myself, "I wish someone would write an article that would step me through the process." The June issue of *Nuts & Volts* just arrived! So, thank you very much. I think it's time to go "swimming."

Greg Lewis

Response: You are welcome, you are welcome, you are welcome!

Thanks for taking time to read the article. I'm glad it was useful to you.

Fred Eady

MORE SWIMMING REVIEWS

I would like to thank you for the well-written article "PCB Basics: From Your Brain to a Finished Board," appearing in the *Nuts & Volts* June 2008 issue. This is exactly the sort of basic how-to article I need to advance my own skills.

I have a question. When you click the "Order Boards..." option, is ExpressPCB smart enough to know whether the board needs to be two layer or four layer and default to what the design actually needs?

Bob Cochran
Greenbelt, MD

Response: Thanks for reading!

When you begin your design, you should set the board type to two or four layer. The program is not smart enough to determine the type of board to use versus the design criteria.

There are things you can't do in two-layer mode that apply only to four-layer boards.

The order program will pick up four-layer things that can't happen in two-layer boards and post an error for you to correct them.

You'll sometimes get the four-layer component in two-layer board errors when you reuse components that have been laid out in a four-layer board design. For instance, if you reuse a component from a four-layer board that has been attached to one of the internal four-layer planes, that will flag an error in a two-layer design as the planes don't exist.

Hope that helps, and again, thanks for reading.

Fred Eady

GIVING THE WRONG SIGNALS

I have enjoyed reading your magazine for a few years now, since all the other electronic magazines have dissappeared. But I have also noticed sometimes that answers to some of the readers questions are not always correct and lead me to believe that whoever gave the answer does not know as much as they think. I have emailed in several times with my views, but have not seen any results. Today, I would like to give a simple comment on the digital TV questions.

I have been an electronics technician/broadcast technologist for about 25 years; I think this gives me some insight to comment on this.

As far as the simple explanation on how they can fit three digital TV signals in the same space as one analog channel — it is really simple. THEY SEND LESS INFORMATION!!!! It has been a couple years since I have worked in the broadcast industry, and there are probably many people out there that can give a more in-depth explanation, but here is mine.

In the early 1990s at one place I worked, we were testing coax cable to handle digital TV signals in the studio environment. The analog bandwidth needed was 6 MHz minimum, the equivalent digital signal ran at 270 megabits per second. End result: You need much more bandwidth to send the same signal in digital format than analog.

This creates large problems. To use

continued on page 92

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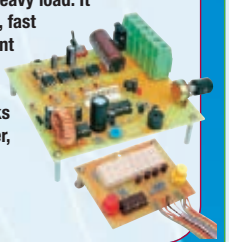

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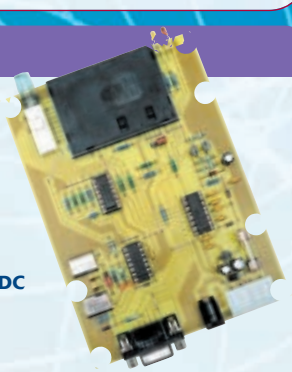
Jaycar cannot accept responsibility for the operation of this device, its related software, or its potential to be used in relation to illegal copying of smart cards in cable TV set top boxes.

Requires 9-12VDC wall adaptor



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■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

FLYING SAUCER: PATENT PENDING

PHOTO BY DANIELLE ZAWOY, UNIVERSITY OF FLORIDA.

■ Artist's conception of a WEAV flying above the Mars surface.

The US Patent Office recently received an application for something that resembles a traditional flying saucer, but the applicant isn't a Martian — the culprit is Assoc. Prof. Subrata Roy, of the University of Florida's Dept. of Mechanical & Aerospace Engineering (**www.mae.ufl.edu**). The design is properly known as a "wingless electromagnetic air vehicle," or WEAV. The innovative part of the concept is that the WEAV will be powered by magnetohydrodynamics, which is basically the science of how electrically conductive fluids — which include plasmas and liquid metals — are affected by magnetic fields. In this case, "the conducting fluid will be created by electrodes that cover each of the vehicle's surfaces and ionize the surrounding air into plasma ... the force created by passing an electrical current through this plasma pushes around the surrounding air, and that swirling air creates lift and momentum and provides stability against wind gusts."

The saucer-like shape serves to increase the area of the air-vehicle interface and maximize lift. A major advantage to this concept is that the vehicle will have no moving parts and the ability to take off vertically, hover, and fly not only in Earth-like atmospheres but also in places like Titan, Saturn's most inviting moon.

Some pretty substantial hurdles exist, though, so don't get prematurely excited. For one thing, it remains to be seen if anyone can create a power source capable of generating enough plasma to raise itself against Earth's gravity. In addition, the plasma creates enough EMI that communicating with the vehicle is highly problematic.

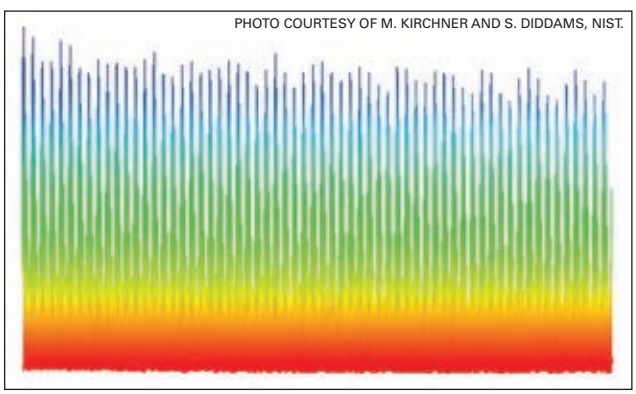
The present design is aimed at a six-inch prototype. But it isn't going to exist in hardware for a while, so if you see a UFO outside your window, you can still jump to extraterrestrial conclusions. But the Air Force and NASA reportedly have expressed interest in the concept, so you never know.

LASER MAY AID SEARCH FOR PLANETS

Also presenting possibilities for space exploration is a laser device developed by scientists at the National Institute of Standards and Technology (NIST, **www.nist.gov**) and Germany's University of Konstanz (**www.uni-konstanz.de**). We're talking about an ultrafast laser that offers a record-breaking combination of high speed, short pulses, and high average power: This dime-sized device produces 10 billion pulses per second, each about 40 quadrillionths of a second in duration, with an average of 650 mW power. As it turns out, the laser — when used as a frequency comb (see **www.nist.gov/public_affairs/newsfromnist_frequency_combs.htm** for a detailed definition) — could provide 100 times the sensitivity of existing astronomical tools used in the search for Earth-like planets orbiting distant stars. In practical terms, this means we should be able to detect starlight "wobbles" created by such planets down to a few centimeters per second rather than the present one meter per second.

Standard frequency combs have "teeth" (see illustration) that are too finely spaced for instruments to read. But the new laser bounces light between sets of mirrors to eliminate some blocks of teeth, thus creating a "gap-toothed" comb that displays only every 10th or 20th tooth. The next step is to incorporate the device in a ground-based telescope or satellite. Other possible applications include remote sensing of gases and precision control of high-speed optical communications.

PHOTO COURTESY OF M. KIRCHNER AND S. DIDDAMS, NIST.



■ Experimental data from a "gap-toothed" frequency comb, false colored to show a power range from low (red) to high (blue).

COMPUTERS AND NETWORKING

ANOTHER BOX FOR BOTTOM-FEEDERS

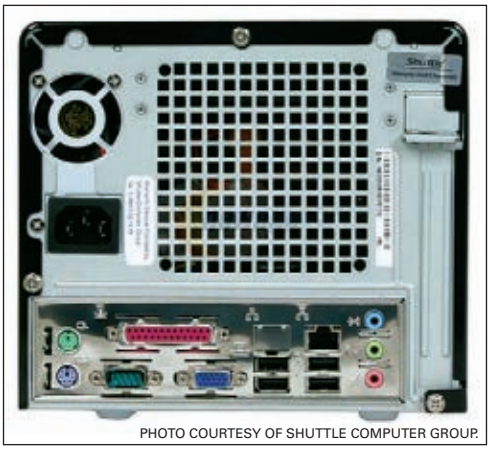


PHOTO COURTESY OF SHUTTLE COMPUTER GROUP.

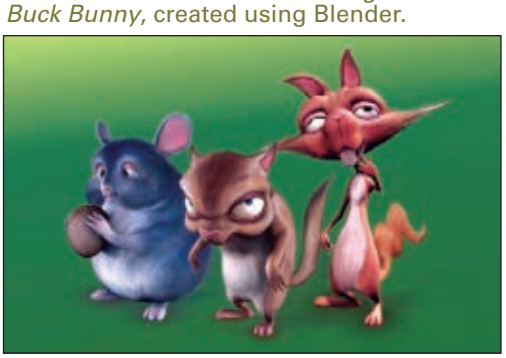
■The business end of a Shuttle K450 computer.

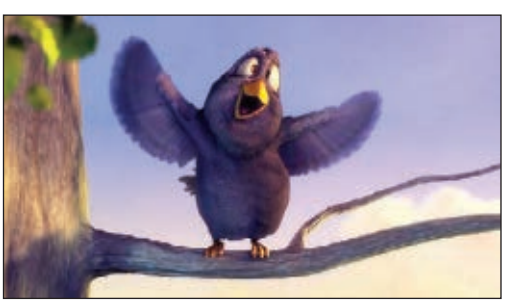
The latest discovery in our never-ending search for el-cheapo computers is the K-4500-RS Perfect Cube Mini from the Shuttle Computer Group (**us.shuttle.com**), US division of the parent company in Taiwan. With a street price starting at $209.99, it looks like a surprisingly formidable little box. The basic unit runs on a Celeron® 430 processor, but a Pentium® dual-core chip is optional. Also standard is 512 MB of RAM (supports up to 2 GB), an Intel® graphics accelerator, high-def audio, four USB 2.0 ports, and an 80 gig hard drive. It comes with Foresight Linux and a one year warranty. And to make it look nice on your desktop, the black front cover has a removable clear panel, behind which you can mount your favorite work of art.

STEP ASIDE, PIXAR

You can spend a lot of money on 3D imaging software, such as 3ds Max ($3,500), Maya Unlimited ($6,999), and Houdini Master ($7,995). But how about a full-featured package released as Open Source software (i.e., for free) under the GNU General Public License? Enter Blender, downloadable from **www.blender.org**. It can be used for modeling, animation, game creation, and a range of other things, and it is available for mainframes to PCs and most operating systems: Windows, Linux, MAC OX, Solaris, and FreeBSD. Blender isn't for the casual user, being complex and reputedly difficult to learn. But for a good example of what can be done if you have enough time on your hands, take a look at "Big Buck Bunny," a video about a congenial rabbit who has to deal with three rude rodents. The movie, generated using Blender on Sun Microsystems (**www.sun.com**) hardware, has been released on 35 mm film and Blu-ray. But you can download it for free at **www.bigbuckbunny.org**. It was given a "special mention" award at Italy's Cyborg Film Festival and, according to Sun's David Folk, "demonstrates that the barriers to entry in the 3D animation world can be lowered tremendously using on-demand computing platforms." If you have dreamed of being the next animation genius, you now have the tools to make the dream come true.

■ Characters from the movie *Big Buck Bunny*, created using Blender.





COMPUTER WITHIN A PEN

■The Pulse smartpen from Livescribe.

Yeah, we've all seen digital pens that capture handwritten notes, double as a mouse, and perform other essentially nonessential functions. But an interesting twist is the Pulse smartpen, a product of Livescribe (**www.livescribe.com**). According to the company, it is "a computer within a pen that captures handwriting and simultaneously records audio and synchronizes it to the writing. Users can simply tap on their notes to replay what was recorded from the exact moment they were writing, so they never miss a word they hear, write, or speak." It also offers (or will offer) a range of general purpose computer functions including games, language translation, personal organization, ebooks, birdwatching assistance, transcription, and a built-in can opener. (Well, maybe not the latter.) The $149 1 GB model stores 100 hours of audio and 16,000 pages of notes. For $199, you can pick the 2 GB version. And even if you don't end up using it, the sleek, charcoal blue anodized unit will make a handsome paperweight.

CIRCUITS AND DEVICES

SUPERCONDUCTOR CABLE ENERGIZED

PHOTO COURTESY OF AMERICAN SUPERCONDUCTOR.

■ LIPA's new power transmission cable.

You don't get to see superconductors in operation every day, but back in April, the Long Island Power Authority (LIPA, **www.lipower.org**) fired up the first high-temperature superconductor (HTS) power transmission cable system in its commercial power grid. The cables shown entering the ground in the photo can carry as much power as all of the overhead lines shown in the background. The 138 kV system can handle 574 MW of power (enough to run 300,000 homes) via the three individual power cable phases running in parallel (150 times the current handled by copper cables of the same size), and it virtually eliminates the typical seven to 10 percent resistance loss. The 2,000 ft (610 m) cable system is cryogenically cooled using a liquid nitrogen refrigeration system. Return

INDUSTRY AND THE PROFESSION

DIG OR DUMP DIRT

Back in June, **glassdoor.com** opened its virtual doors with the aim of providing inside information on employers, salaries, and other subjects. So far, it's concentrating on San Francisco Bay area tech companies, but expansion into other regions and industries is in the works. If you want to find out what it's really like to work for a prospective employer, or warn others about how you're treated by yours, all you have to do is sign up (for free) and contribute a review or salary report. In return, you get access to everyone else's reviews and salaries. Should make interesting reading, although accuracy will be iffy until the site builds up a large enough database to marginalize the statistical effects of disgruntled employees and pathological liars.

US REMAINS COMPETITIVE

Contradicting a common perception that the old red, white, and blue is losing its competitive edge in science and technology, a recent RAND Corporation study revealed that the US still accounts for 40 percent of the world's total spending on scientific R&D, employs 70 percent of the Nobel Prize winners, and hosts 75 percent of the top 40 universities. Much of the credit belongs to the contributions made by students, scientists, and engineers from other countries.

"Much of the concern about the United States losing its edge as the world's leader in science and technology appears to be unfounded," said Titus Galama, co-author of the report and a management scientist at RAND, a nonprofit research organization. "But the United States cannot afford to be complacent. Effort is needed to make sure the nation maintains or even extends its standing."

The study offers a range of recommendations for maintaining our lead, including making it easier for foreign-born graduates to remain here, facilitating immigration of highly skilled labor, improving K-12 scientific education, and boosting our ability to learn from science centers in Europe, the Far East, and other areas. For a copy of the 188-page report, go to **www.rand.org/pubs/monographs/MG674/**. It'll run you $28.80 with the Web discount.

ANOTHER WIN FOR THE GOOD GUYS

Last October, 21-year-old hacker Gregory King was arrested in the FBI's "Operation Bot Roast." He was tracked down after launching Valentine's Day distributed denial-of-service attacks against antiphishing website CastleCops and KillaNet, a forum for gamers and graphic designers. As agents were breaking down his door, King stashed his laptop in the backyard, but the authorities eventually located it and charged him with two counts of "transmitting code to cause damage to a protected computer." Using a botnet of about 7,000 hacked computers, King had bombarded CastleCops with a 969 Mb/s datastream. If the volunteer-run organization had been charged for the bandwidth, it would have been forced to close down. King is scheduled for sentencing on September 3rd, and the plea agreement calls for him to be put away for two years. A pat on the back goes to US District Judge Lawrence Karlton.

on investment may take a while, as the project cost $58.5 million, about half of which was funded by the Department of Energy. But the mission is to "modernize the electric grid, enhance security and reliability of the energy infrastructure, and facilitate recovery from disruptions to energy supply." Sounds like a worthy goal.

HEFTY DVR STORAGE

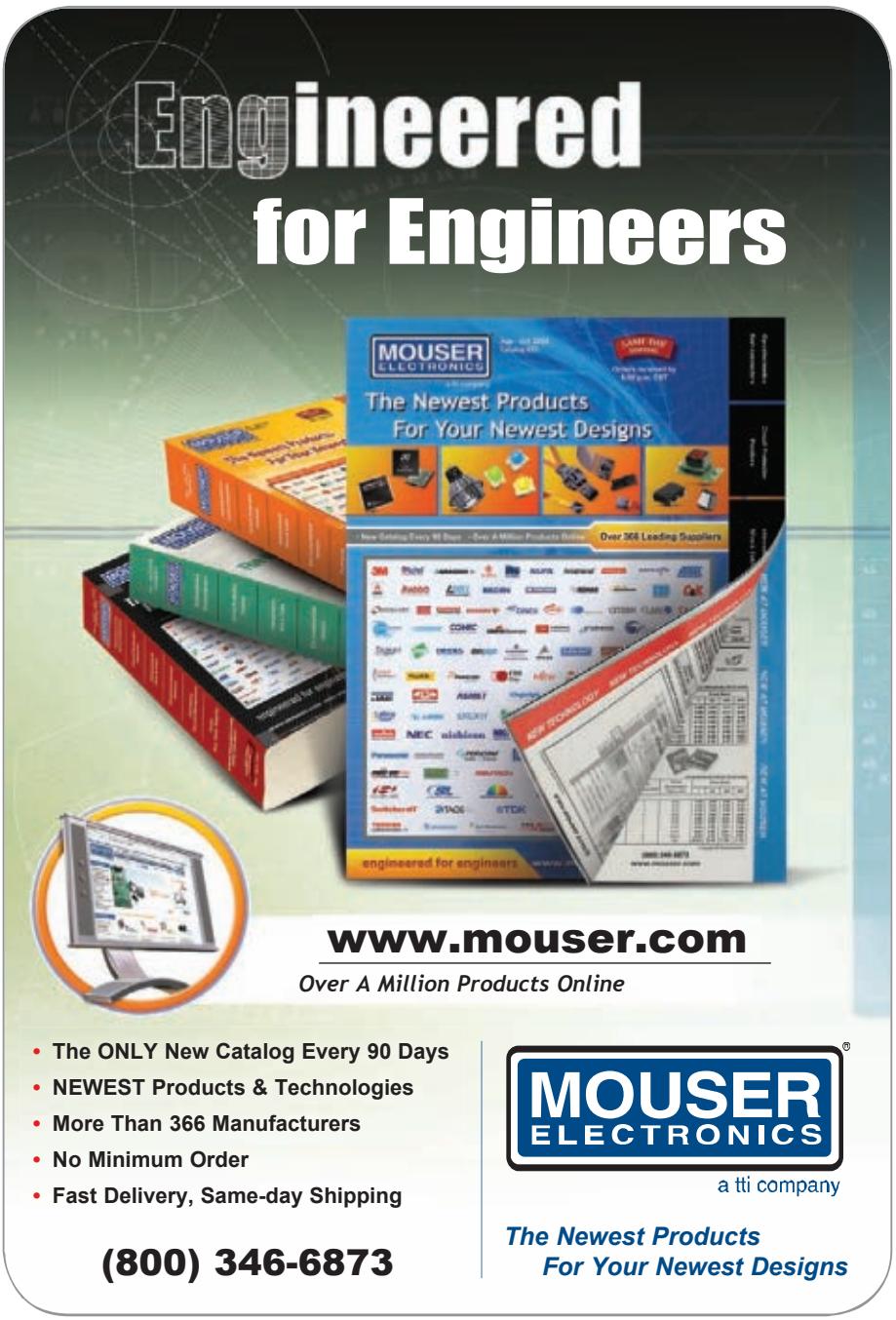
You're probably familiar with Seagate's line of hard drives aimed at computer data storage, but the company recently announced the Seagate® Showcase™, a series of products that extend the storage capacity of DVRs. Designed for compatibility with Motorola's eSATA capable high-definition products (but you also can connect via a standard USB 2.0 cable), they are slated for market soon, perhaps by the time you read this. The boxes will initially come with 1 TB of storage, which translates into 200 hr of HD movies or 1,000 hr of standard-def TV. The Showcase family features Seagate's Pipeline HD™ series of hard drives.

The Pipeline drives are designed specifically for DVRs, providing top-notch high-definition performance and capacity with "bedroom-quiet acoustics," low-power operation, and the ability to support up to 12 simultaneous HD streams. The drives are Windows Vista certified, making them suitable for home media centers. The list price has not been divulged, but the product does come with a one year warranty and free tech support even after the warranty expires. You can check for price and availability at **www.seagate.com**.

60-V LED DRIVER

Linear Technology (**www.linear.com**) recently announced the LT3755 device, a 60V output, high-side current sense DC/DC converter designed to drive high current LEDs. It has a 4.5V to 40V input range, making it useful for such applications as automotive, industrial, and architectural lighting. Using an external N-channel MOSFET, it can drive as many as 14 1A white LEDS from a 12V input to deliver over 50W. The high-side current sense allows it to be used in boost, buck, buck-boost, or SEPIC and flyback topologies. Frequency can be adjusted between 100 kHz and 1 MHz and, because the device is better than 94 percent efficient in boost mode, no heatsinking is required.

The LT3755 uses True Color PWM™ dimming to deliver constant color with a dimming range of up to 3,000:1. Two versions are available: the standard LT3755, which offers an open LED status pin; and the LT3755-1, which replaces the pin with a frequency synchronization pin; In production quantities, they'll run you about $2.75 each. For $3.15, you can get an extended-temperature version. **NV**



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BY RON HACKETT

GETTING STARTED WITH THE PICAXE-28X1 MICROCONTROLLER

IN ESSENCE, THE PICAXE-28X1 IS LIKE A 28X ON STEROIDS. It's pin-for-pin compatible with the 28X and all the 28X commands will function correctly on a 28X1. In other words, if you have an existing 28X circuit, it will function exactly the same with a 28X1 installed. This is a good thing, because Revolution Education considers the 28X to be obsolete and has discontinued it. Amazingly, the new 28X1 is about the same price as the old 28X.

The PICAXE-28X1 has so many improvements and powerful new features that it's hard to know where to begin. In order to avoid the risk of information overload, I have decided on a two-phase approach. In this installment of the Primer, I'll present a brief overview of most of the new features and then go into more detail on a couple of them that we will be using right away. In future Primer installments, we'll explore each new feature in depth as we have a need to use it in a project.

HARDWARE IMPROVEMENTS

Let's begin by taking a look at the memory and storage capacity of the 28X1. Figure 1 presents a comparison of the relevant features of all the current PICAXE processors; a quick glance will give you some idea of the scope of the 28X1's improvements in this area. Most of the information in Figure 1 is self-explanatory but a couple of points are worth noting.

First of all, the general-purpose byte variables (b0 to b13 in all the previous PICAXE chips) have been doubled to b0 to b27 in the 28X1. If you have ever run out of variables in a program, you will appreciate how significant this improvement is. Also, the 28X1 includes an entirely new 128-byte storage area (the scratch-pad) that can be used for additional storage; it's especially useful for tables and arrays as we will see in a future installment of the Primer.

Finally, although it's not included in Figure 1, it's worth mentioning that the maximum system speed has been increased from 8 MHz in the earlier processors to 20 MHz in the 28X1. System speed options have also become much more flexible — we'll get to that in detail later in this installment when we take a look at the new resonator features of the 28X1.

	08M/14M/20M	18X	28X1/40X1
BASIC Program Memory	~ 80 Lines	~ 600 Lines	~ 1000 Lines
General Purpose Variables	14	14	28
Storage Variables (peek/poke)	48	96	95
Scratchpad Variables (get/put)	-	-	128
Special Function Variables	3/4/4	4	7
EEPROM Data Storage	256 - program	256	256

■ FIGURE 1. PICAXE processor memory comparisons.

SOFTWARE IMPROVEMENTS

Figure 2 presents the pin-out of the 28X1; in it, some of the major new software functions are highlighted in a larger bold font. We will consider the pins in numerical order, so the first new feature that jumps out is "ULPWU" (pin 2), which is an acronym for the new "Ultra Low-Power Wake-Up" feature. We will explore the ULPWU in some detail in a future installment of the Primer when we begin working on a 28X1 battery-powered data-logging system, but for now all we need to know about it is that ULPWU provides a means for greatly reducing power consumption.

Next, we see the "timer clock" function on pin 11. This feature

accesses a new 16-bit background timer/counter, with a user-accessible timer variable. It can operate in one of two modes: timer mode and counter mode. In timer mode, your program can set up a timer that runs in the background and increments at a frequency you can specify, e.g., once per second. "In the background" means that your program can go about its business and check the timer variable periodically to determine its current value. In other words, it's possible to include a real-time clock function in your program without needing an external clock chip; we will do exactly that in the near future. In counter mode, your program can count the number of pulses received on input 0 (again, in the background) so it can be carrying out other tasks simultaneously.

Pins 13, 22, 23, and 25 are all used to implement the 28X1's new hardware PWM command which is used for advanced motor control and is a more powerful alternative to the more traditional "pwmout" command (pins 12 and 13) which we will also implement in an upcoming Primer installment.

Pins 14, 15, and 16 provide the necessary I/O lines to implement the standard three-wire SPI protocol. SPI is a much faster alternative to RS-232 serial communications; many inexpensive peripheral SPI chips are readily available to carry out a variety of communications functions. For example, the Max7219 is a 24–pin chip that can be used to interface with up to eight seven-segment LED displays. An upcoming Primer I/O project will use the MAX7219 to implement a stand-alone, four-digit seven-segment LED display.

I've saved the best until last — pins 17 and 18 can now be used in conjunction with the new hardware-based "hserin" and "hserout" commands. These commands support much higher serial baud rates than the older serin and serout commands (which are also still available). More importantly, hserin can operate in the background and automatically save the received data in a special area of memory. This means that your program no longer has to sit and wait for serial input; it can be doing other tasks while serial data is being received and when it's convenient, it can retrieve the received data for processing.

In addition to the new features whose presence is clearly announced on the 28X1's pin-out, there are many additional new commands and improvements to older commands that can be discovered by reading the documentation. Don't forget, you will need to install the latest version of the Programming Editor software (available at **www.rev-ed.co.uk/picaxe**) to be able to use these new features in your programs. We'll explore the vast majority of them in detail as we need them in our various I/O projects in the coming months. In the meantime, the following summary list of the major improvements in the 28X1 should whet your appetite:

- **ADC Commands (calibadc, calibadc10):** In the past, ADC readings have been based on the supply voltage. Therefore, in battery-powered systems, changes in the supply voltage produced inaccuracies in the ADC readings. The new commands allow access to a fixed, internal 0.6V supply for increased accuracy.

- **Data Storage Table (table, readtable):** Allows for a 256-byte data lookup table in EEPROM; we'll find it useful for LCD menu text.

- **I²C Commands (hi2cin, hi2cout, hi2csetup):** The 28X1 is able to function as either an I²C master or slave which (among other advantages) allows for the networking of multiple 28X1 processors.

- **IR Commands (irin, irout):** IR communication can now be implemented on any I/O pin. Also, the irin command includes a "timeout" feature so your program won't hang if data is not received.

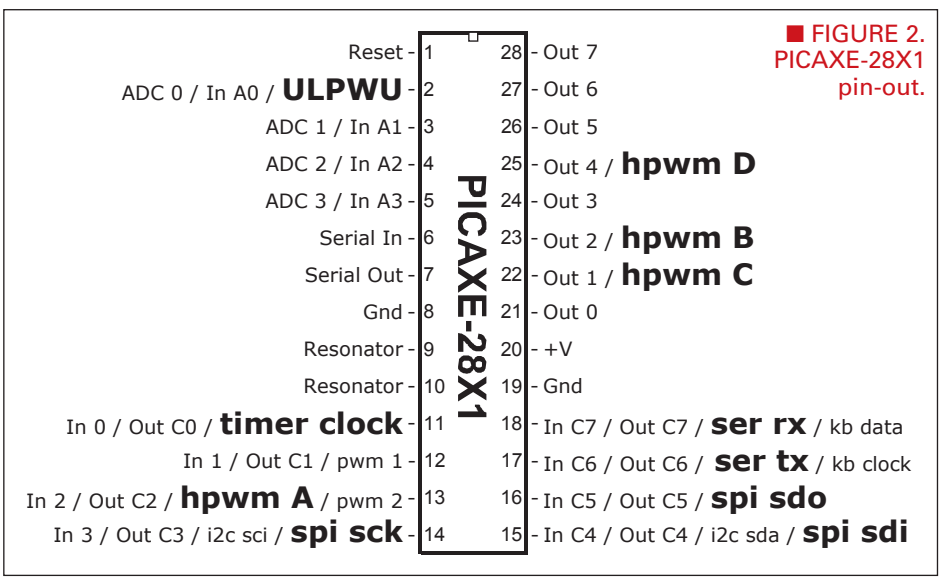
- **Keyboard Input (kbin):** Similar to the older "keyin" command, but now also includes a timeout feature.

- **Memory Access (get, put):** Provide access to the 128-byte scratchpad memory area for additional data/variable storage.

- **One-Wire Commands (owin, owout, readowsn):** Provides full support for the 1-Wire protocol on any I/O pin.

- **Power-reduction Commands (disablebod, enablebod, hibernate):** Implements the new ULPWU feature. We'll explore disablebod and enablebod next.

- **Serial Communications**



■ FIGURE 2. PICAXE-28X1 pin-out.

(disconnect, reconnect, serin, serout, serrxd, sertxd): The disconnect command stops the 28X1 from looking for a new program download, which enables your program to use the download cable for data communications (using serrxd and sertxd) with your PC (e.g., via a terminal program). The serin command now includes a timeout feature so your program won't hang if data is not received. Also, the new hardware serial commands (discussed previously) allow for automatic serial input in the background.

• **Sound Output (play, sound, tune):** Sound and music output can now be implemented on any output pin.

• **SPI Commands (hspiin, hspiout, hspisetup):** Enables higher communication speeds.

• **Timer Commands (settimer, settimer count):** New 16-bit background timer/counter.

There are also several significant additions in the area of mathematical computations. We don't have space to list them here, but we'll get to many of them in upcoming installments of the Primer. All of the new features and commands are covered in the documentation, especially Part 2 of the PICAXE manual — have a read!

RESONATOR ENHANCEMENTS

The 28X1 isn't the first PICAXE to support an external resonator; each of the earlier 28-pin chips did so, as well. However, the 28X1 provides more external resonator choices. Also, with a top speed of 20 MHz, the 28X1 is the fastest PICAXE currently available (40 MHz X2 processors are already being developed). Of course, the option of increased speed is in itself a big improvement. However, the 28X1's resonator flexibility is an even more significant advance.

In addition to the external resonator choices of 20, 16, 10, 8, and 4 MHz, the 28X1 also supports internal oscillator speeds of 8, 4, 2, and 1 MHz, as well as 500, 250, 125, and 31 kHz. What's so great about that, you might ask, and why would anyone ever want to run a program at 31 kHz, anyway? Well, for any CMOS processor (which includes all the PICAXE chips), power consumption is directly proportional to processor speed — so slower program speed goes hand in hand with lower power requirements. In other words, if your project is battery powered, the more you can slow down the speed of program execution, the longer your batteries will last.

A LITTLE EXPERIMENT

As you already know, once we have completed a few of our upcoming I/O projects we're going to develop a battery-powered data-logging system, so the prospect of a significant reduction in power consumption is of special interest. To get some idea of just how much power we might be able to conserve, I carried out a little experiment with a simple 28X1 circuit, but before we get into the details and the results, I need to introduce a term that may be new to some readers. The 28X1 has a feature called "brownout detection" or BOD; its function is to cleanly reset the chip in the event of a power brownout (i.e., a temporary drop in the input voltage). It's a great feature for line-powered circuits, but not really necessary with battery-power, and it does require a fair amount of power to operate. Fortunately, the 28X1 supports software commands to enable or disable BOD (enablebod and disablebod).

I had three goals in mind when I set up my experiment. The first was to measure the 28X1 supply current at each of its internal resonator speeds. I focused on the internal resonators because the Microchip data sheet for the PIC16F886 (the chip on which the 28X1 is based) contains data that shows that the external resonators consume significantly more power, even at the same speed (i.e., 4 MHz external vs. 4 MHz internal).

The second goal was to determine the magnitude of the supply current reduction obtained by disabling BOD at each internal speed. Finally, since power consumption also decreases with lower supply voltages, I took all my measurements with a five-volt power supply and then repeated the process with a 3.3-volt supply. When I recorded each measurement, I made sure that the 28X1 wasn't powering any external components (e.g., an LED) because the additional power usage would confound the results.

If you examine the resulting data (presented in Figure 3), you can see that all three variables influenced power consumption exactly as we would expect: For both supply voltages, lower resonator speeds resulted in lower supply currents; compared

	5.0-volt Power Supply		3.3-volt Power Supply	
Speed	BOD Enabled	BOD Disabled	BOD Enabled	BOD Disabled
8 MHz	1.82	1.75	1.07	1.03
4 MHz	1.07	0.98	0.64	0.59
2 MHz	0.68	0.60	0.42	0.38
1 MHz	0.49	0.41	0.31	0.27
500 kHz	0.39	0.32	0.25	0.21
250 kHz	0.35	0.27	0.23	0.19
125 kHz	0.32	0.24	0.21	0.17
31 kHz	0.11	0.03	0.06	0.02

Note: See text for important information about the 28X1 Brown-Out Detection feature.

■ FIGURE 3. 28X1 internal resonator supply currents.

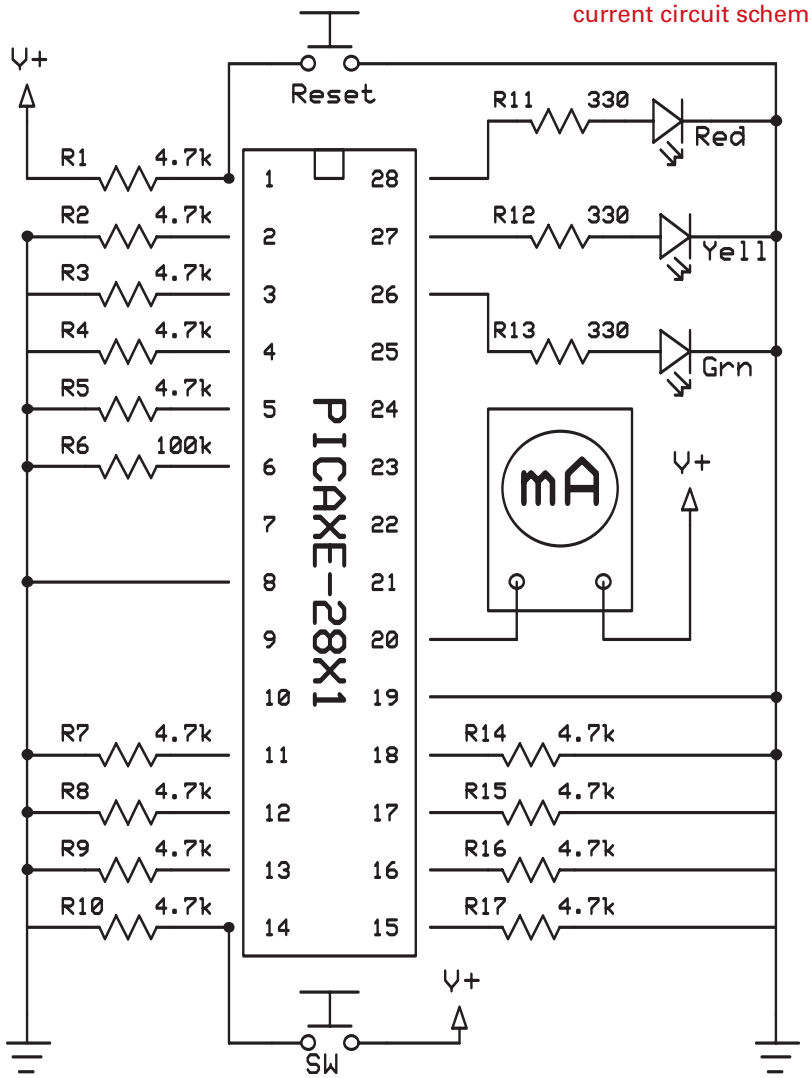
to the 5.0-volt supply, the 3.3-volt supply consistently resulted in lower supply current at each speed; and, disabling BOD further reduced the supply current at every speed. So, when we get to our battery-powered data-logger project, we'll definitely use the slowest possible speed (but not 31K, unless we can resolve the problem described later in this installment).

If you would like to make your own supply current measurements, a schematic of the circuit I used is presented in Figure 4. A close-up photo of the breadboard is shown in Figure 5 and Figure 6 is a photo of the entire setup including the multimeter I used for the current measurements. In the schematic, I am assuming you are using a separate programming adapter board, so I have not included that portion of the circuitry. Also, note the pull-down resistors on all of the unused input pins. Without them, the inputs would float and possibly change from a high state to a low state due to random static charges.

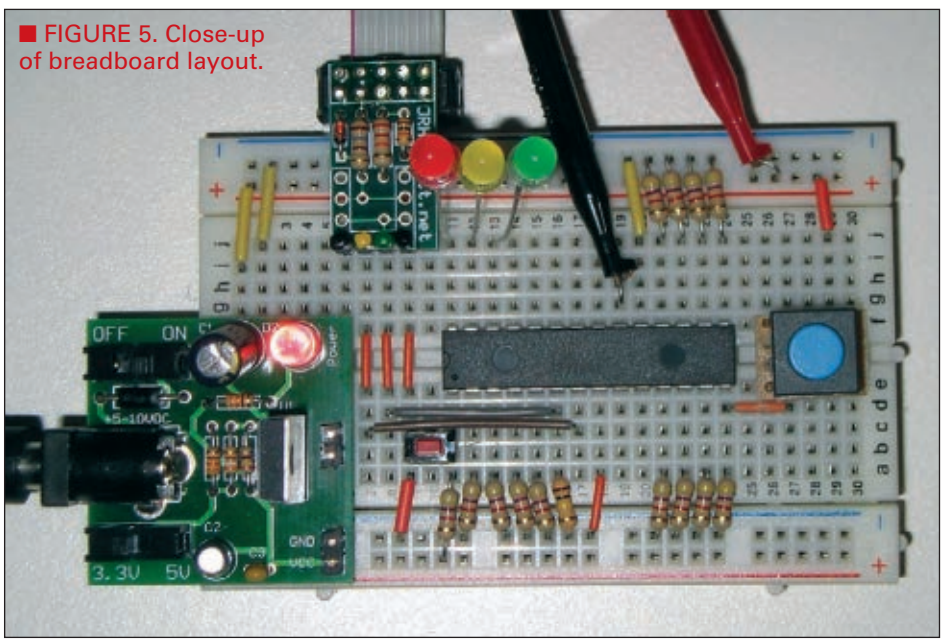
Whenever a CMOS input changes state, it consumes power, so to avoid any unnecessary power consumption I grounded all the unused inputs. This is a good idea in any circuit (even if you don't care about the power consumption) because it can also reduce unnecessary noise in the supply lines. The push-button switch on input 3 allowed me to keep the 28X1 at its current speed while I wrote down the supply current measurement; pressing the button advanced the 28X1 to its next speed setting and the next supply current measurement (except at 31K — we'll get to that problem shortly). The software I used is too long to include in the Primer, but it's available for download at the *N&V* website (**www.nutsvolts.com**); look for "CurrentTest.bas."

The 28X1's powerful and flexible resonator features can sometimes result in a minor inconvenience that you should keep in mind. Whenever you initiate a program download to a PICAXE chip, the Programming Editor software requires that the target

■ FIGURE 4. 28X1 supply current circuit schematic.



■ FIGURE 5. Close-up of breadboard layout.



PICAXE is running at 4 MHz. This is never a problem at power-up or reset; in those two cases, the 28X automatically defaults to its 4 MHz internal resonator. However, if the 28X1 is currently running software that has changed the speed to anything other than 4 MHz, you may get a "hardware not found" error and the program will fail to download. The solution is to do the following: Hold down the 28X1's reset button, initiate the download, and then release the reset button — the program should download successfully.

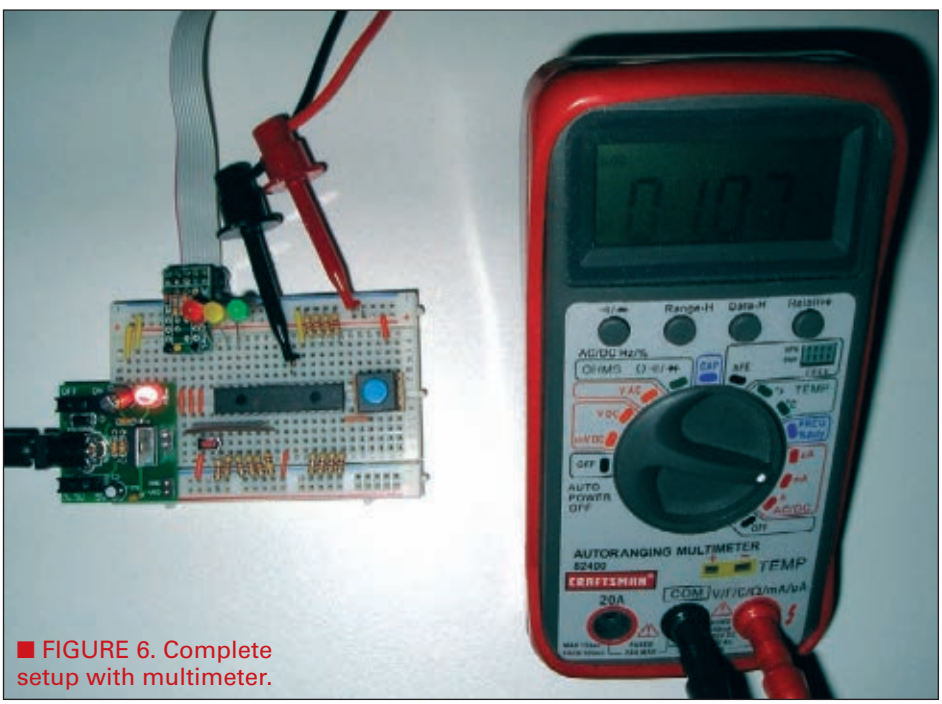
PROBLEMS, PROBLEMS, PROBLEMS ...

Actually, my little experiment didn't proceed nearly as smoothly as the results might suggest. As I carried out the measurements, I encountered two very surprising and perplexing problems. First, every measurement I made with the disablebod command in effect was higher than the corresponding measurement with enablebod in effect. This, of course, is exactly the opposite of what it should be, and I spent a fair amount of time examining both the hardware and software to see if I could find the source of the problem. Finally, in desperation (I hate to admit I can't figure something out on my own!) I posted a message on the PICAXE forum (**www.picaxeforum.co.uk**) detailing the problem. Within a day or so, there were several responses confirming my results, and by the second day a response from "Technical" (the RevEd guru who moderates the forum) indicated that the strange results were due to a bug in the 28X1 software and that the bug would be corrected in the next update to the Programming Editor software. In the meantime, I'll just use the two commands as if their meanings were reversed, which is what I did to obtain the data presented earlier in Figure 3. Of course, when the bug is corrected, I'll need to reverse the commands again to straighten things out.

This little saga is one indication of just how helpful the PICAXE forum can be and how responsive RevEd is to input from its user base. If you're not already a forum member, I would highly recommend joining. The members are very knowledgeable and willing to help. If you have a question, first search the archives because your problem may have already been addressed. If you can't find what you're looking for, post a message with a thorough description of your hardware and software setup and the nature of the problem, and you're very likely to get some helpful feedback.

The second problem I encountered is even more perplexing than the reversed BOD commands. As I mentioned earlier, I used a push-button on input 3 to give myself time to write down the current readings. After each internal resonator speed change, the program idles in a loop until the button is pressed (at least that's what I intended). The idling works properly at every speed except 31K; in that case, the software seems to reset itself. My deadline for submitting this article to *N&V* arrived and I still haven't figured out what's going on. I haven't posted the problem on the forum yet, but at some point I may have to give in and ask for help again! In any case, I'm sure we'll revisit this issue in future installments of the Primer, but even if 31K turns out to be unsuitable for our battery-powered data-logger, it's great to know that we can reduce our supply current by 90% by simply disabling BOD (with whichever command works!), switching to a 3.3-volt supply, and turning down the internal resonator speed from 8 MHz to 125 kHz. In order to get a rough estimate of how long we might expect a battery-powered 28X1 system to operate, I made a couple of assumptions and calculated what I think is a very conservative estimate of battery life. I chose the Eveready Energizer six-volt lantern battery (#528 or 529) for two reasons: It has a huge capacity (26,000 mAh — see **http://data.energizer.com**) and six volts should give us more than enough headroom to supply a 3.3-volt low-dropout regulator.

As we saw in Figure 3, at 3.3 volts the 28X1 will draw 0.17 mA at 125 kHz with BOD disabled. Of course, we'll also want to take various measurements (e.g., temperature) and perform other tasks occasionally, so let's triple that and assume 0.5 mA current draw on average. A full day of operation will consume 24h x 0.5 mA = 12 mAh, so we can expect 26,000/12 = 2167 days (almost six



■ FIGURE 6. Complete setup with multimeter.

years) of full-time operation. In addition, the 26,000 mAh capacity is based on typical current drains that are much higher than our relatively low drain of 0.5 mA, so the actual capacity of the battery should be considerably higher and the theoretical lifespan may be even longer than six years.

On the other hand, temperature fluctuations and other real-world factors will probably decrease the battery's lifespan, but even four or five years would be more than adequate. We'll also have for our data logger monitor its own supply voltage, so we'll be able to determine if our estimate turns out to be reasonably accurate.

Finally, we haven't even considered how we can use the new "hibernate" command to further reduce the supply current (but, trust me, we will). By the time we're finished with our project, it will probably outlast the Energizer Bunny!

WHAT'S NEXT?

That's it for our overview of the major new features of the 28X1. It's an impressive chip and in future installments, we'll delve more deeply into the details of many of the features we only touched on this month. If you want to get a head start with any new feature or command, don't forget that Part 2 of the PICAXE Manual contains the complete documentation — there's lots of valuable information in there.

In the next installment of the Primer, we'll develop our first I/O device for use with the 28X1 (or any processor, for that matter) — a multi-function infrared board capable of sending and/or receiving IR signals in the SIRC protocol, as well as functioning as an object detector for robots or home control projects. We will also explore the 28X1's new hserin command, which can operate automatically in the background while our program is tending to other matters. In the meantime, if you want to review the basics of PICAXE infrared communication, take a look at last February's column. **NV**

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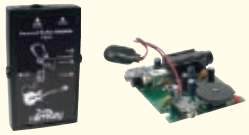

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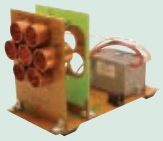

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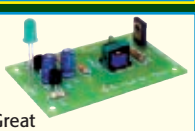

The kit has a pulsing 80 volt tickle output and a mischievous blinking LED. And who can resist a blinking light?! Great fun for your desk, "Hey, I told you not to touch!" Runs on 3-6 VDC

TS4 Tickle Stick Kit $12.95

Super Snoop Amplifier

Super sensitive amplifier that will pick up a pin drop at 15 feet! Full 2 watts output. Makes a great "big ear" microphone. Runs on 6-15 VDC

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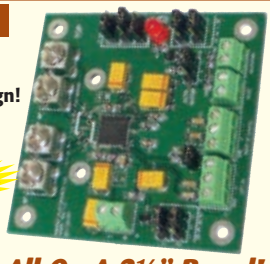

- ✔ 2 independent 20 watt amplifiers in one SMT package!
- ✔ Super efficient Class D spread spectrum design!
- ✔ Built-in click and pop suppression!
- ✔ Selectable gain from +22dB to +36dB!
- ✔ Logic level mute and shutdown!
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- ✔ Built-in thermal protection!
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And at 40 watts, you're probably already wondering about the heatsink requirements to dissapate the heat, right? Stop wondering, there's no heat, so there is no heatsink required! And all that power is generated in a single SMT device the size of your thumbnail on a small 2½" square board!

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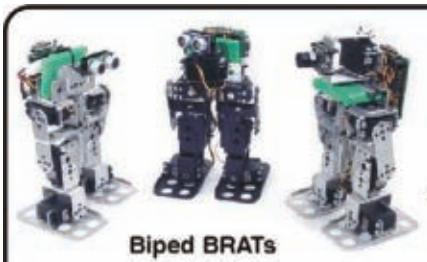
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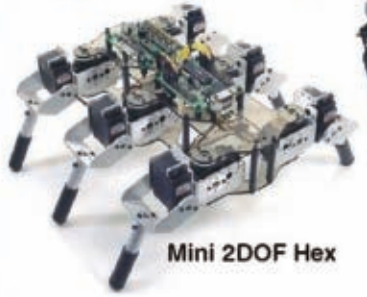
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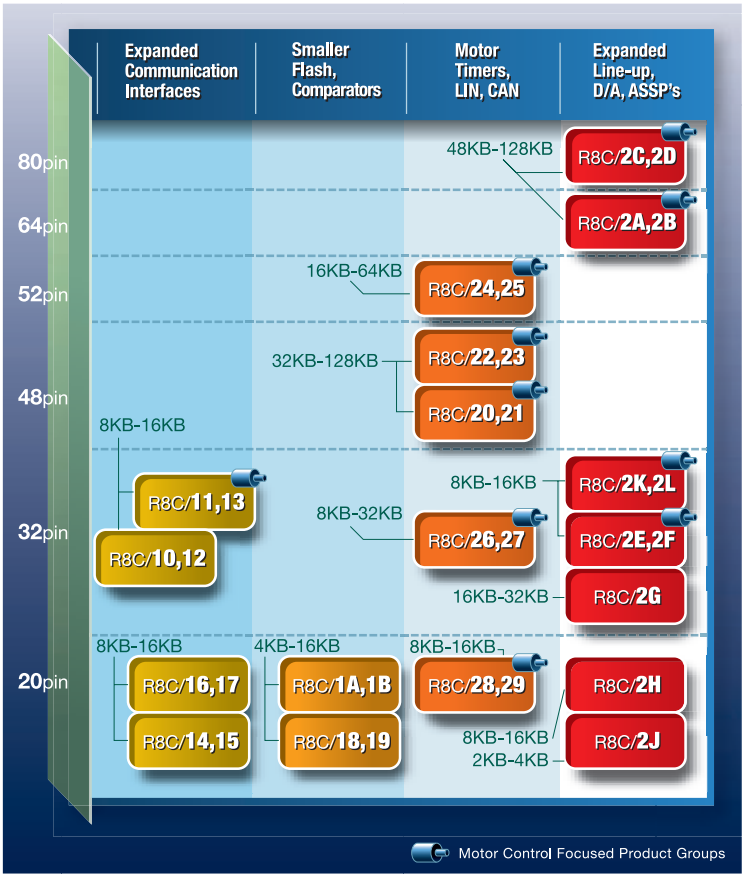

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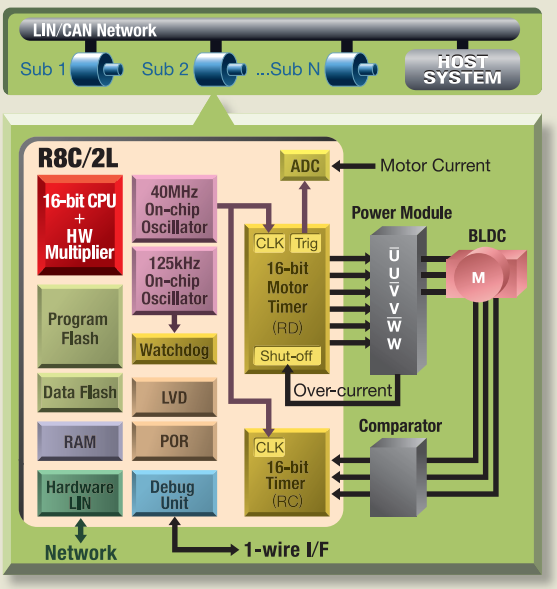

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*Source: Gartner (March 2007) "2006 Worldwide Microcontroller Vendor Revenue" GJ07168

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Q&A

WHAT'S UP:

Join us as we delve into the basics of electronics as applied to every day problems, like:

- ✓ Fly Zapper
- ✓ Vacuum Tube Circuit
- ✓ Solar Tracker

■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:
Q&A@nutsvolts.com

RAILROAD CROSSING LIGHT CONTROLLER

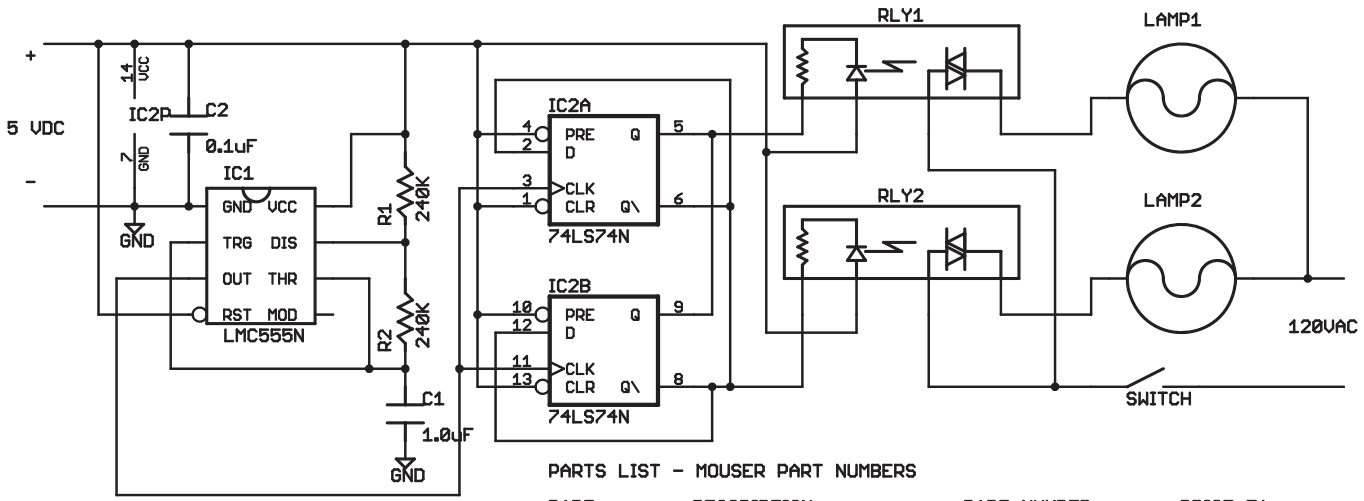
Q I am a volunteer worker/helper at a small local history museum located in Tullahoma,TN. We have a two arm RR crossing light that has been modified with small 110V holders and lamps. I would like to buy/build a controller to alternately light the lamps so that when one goes out, the other will come on. Do you happen to have any ideas?

— Greg Klein

A This calls for a flip-flop. I have used a 555 oscillator driving an SN74LS74 and two solid-state switches (see Figure 1). The oscillator is designed to run at 2 Hz, but you may want to make the frequency variable by replacing R2 with a rheostat connected 500K pot. The SN74LS74 is a dual D type flip-flop and I have connected them in parallel to give more drive to the solid-state switch. The output is arranged to pull down because TTL does not pull up very well. The switch is an opto triac rated at two amps, so it will operate a 100 watt lamp with no problem. The rocker switch mounts in a rectangular hole; you will have to file it to fit, and the toggle switch mounts in a round hole — just drill it. A five volt power supply is needed and the power is low, under 1/2 watt. If you don't have a spare kicking around, this $8.70 unit from Mouser will do: 826-DA4-050US.

AUTOMATIC ON/OFF SWITCH

Q My project is to design and build an automatic on/off circuitry for a remotely located audio amplifier. The



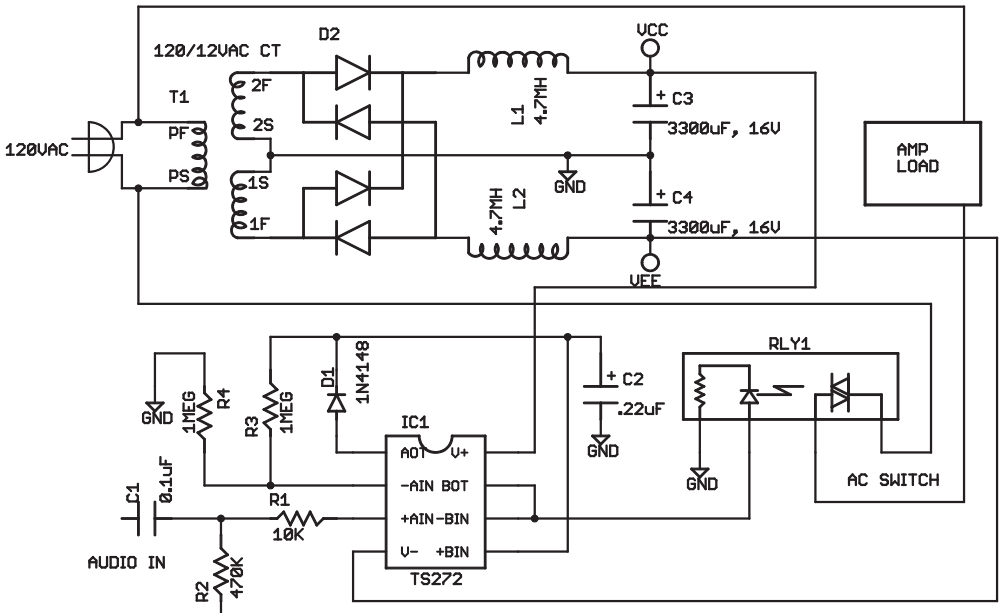
PARTS LIST - MOUSER PART NUMBERS

PART	DESCRIPTION	PART NUMBER	PRICE EA
C1	1.0 uF, 5%, FILM	531-BQ074D0105J	0.44
C2	0.1uF, 5%, FILM, 50V	531-BQ014D0104J	0.12
R1, R2	240K, 1/4W, 5%	660-CF1/4C244J	0.05
IC1	555 TIMER, CMOS	511-TS555IN	0.43
IC2	DUAL D TYPE FLIP-FLOP	595-SN74LS74AN	0.52
RLY1, RLY2	OPTO TRIAC, 2A, 120VAC	653-G3M203PDC5	9.64
SWITCH	SPST, ROCKER, 15A	629-AA111B11	1.18
SWITCH	SPST, TOGGLE, 15A	642-631NH2	5.66

■ FIGURE 1

function is to switch the 120 VAC on and off with a device that is triggered by a three volt audio signal from the preamp. A shielded cable will deliver the signal to the automatic switch. Since a portion of the circuitry is always exposed (AC) and it will be remotely located with the amplifier, I wish to use good quality components. Could you suggest some alternatives. My assumptions include a high impedance input to the triggering device feeding an electronic and/or electromechanical switching device. Surface-mount devices are not a necessity. Thanks in advance for your assistance.

— Paul Lunn



PARTS LIST – MOUSER PART NUMBERS

PART	DESCRIPTION	PART NUMBER	PRICE EA
T1	XFMR, 12.6VCT, 100MA	41FG100	2.74
D1	DIODE, 60V, 0.1A	583-1N4148-B	0.03
D2	BRIDGE RECT. 50V, 1A	583-DB104	0.44
L1, L2	4.7MH, 12 OHMS, 100MA	434-01-472J	0.95
C1	0.1uF, 50V, FILM	140-PF1H104K	0.24
C2	0.22uF, 50V, FILM	140-PF1H224K	0.36
C3, C4	3300uF, 16V, ELECTROLYTIC	140-XRL16V3300-RC	0.67
R1	10K, 1/4W, 5%	271-10K-RC	0.9/10
R2	470K, 1/4W, 5%	271-470K-RC	0.9/10
R3, R4	1MEG, 1/4W, 5%	271-1.0M-RC	0.9/10
IC1	DUAL OP AMP, CMOS	511-TS272IAN	1.00
RLY1	OPTO TRIAC, 120VAC, 5A, ZERO CROSS	653-G3A-205B-DC5	12.98
	HEAT SINK FOR OPTO TRIAC	653-Y92B-A100	11.61

■ FIGURE 2

A Since the audio is being used to turn the power amp on, and since the signal will vary in amplitude, I have designed a time delay turn off when the signal goes away of about one second (see Figure 2). If it is possible that the audio will have quiet times exceeding one second, you will want to increase C2. The design includes the power supply which provides ±8V volts to the switch circuit. I included L1 and L2 to reduce current spiking and make the supply quieter.

U1 is a dual op-amp; the first stage is a half wave rectifier with a gain of two. With a three volt peak input, the capacitor, C2, will be charged to six volts. The second stage is a unity gain buffer to drive the opto triac switch. The triac is a zero crossing switch, so it should not produce much noise. The opto triac specs are: must turn on at four volts input and must turn off at one volt input. I included specs for a heatsink, although I doubt it will be needed. From an initial charge of six volts, it takes about one second to get down to one volt. The resistor, R1, is for static protection; it has no effect on gain. If the preamp output is ground referenced, C1 and R2 could be eliminated.

AUDIO LEVEL ADJUST CIRCUIT

Q I have a whole-house audio system that I'd like to connect to two different TVs as audio sources. The problem is, the TV line level audio out is considerably lower than my other components (CD player, FM radio, etc.) and is not adjustable. So when I switch to the TV source, I have to turn up the room volume. Then when I switch back to the radio or CD player, the audio blares out the speakers if I forget to turn down the room volume. I've looked at some of the electronic kit suppliers, but I've not seen anything like this.

Can you recommend a circuit for a two channel audio level shifter with (I'm guessing) a unity-to-5x gain adjustment? Something with a frequency response as good as or better than HD TV audio? A single chip amp would be fine since it does not need to have a high power output and my preference would be for thru-hole technology as my eyes are not what they used to be.

— Jon Wilbert

A Two channel mixer with adjustable gain ... piece of cake! The signal is undoubtedly stereo, so two pairs of op-amps are needed. Separate volume control for each channel is provided (see Figure 3). Most audio devices nowadays use RCA jacks, so I included those in the parts list. The power supply can be 12 volts (±6V) or use the power supply of Figure 2 (±8V). The parts list is for a 12 volt DC wall wart, but if you have one in your junk box that is between 10 and 16 volts, use that. If you use the power supply in Figure 2, R1 and R2 are not needed. The gain in each channel is

maximum 5 and minimum just under unity. The op-amp unity gain bandwidth is 3.5 MHz so that is not a concern and distortion will be nil as long as the amplitude of the output does not exceed VCC-two volts peak.

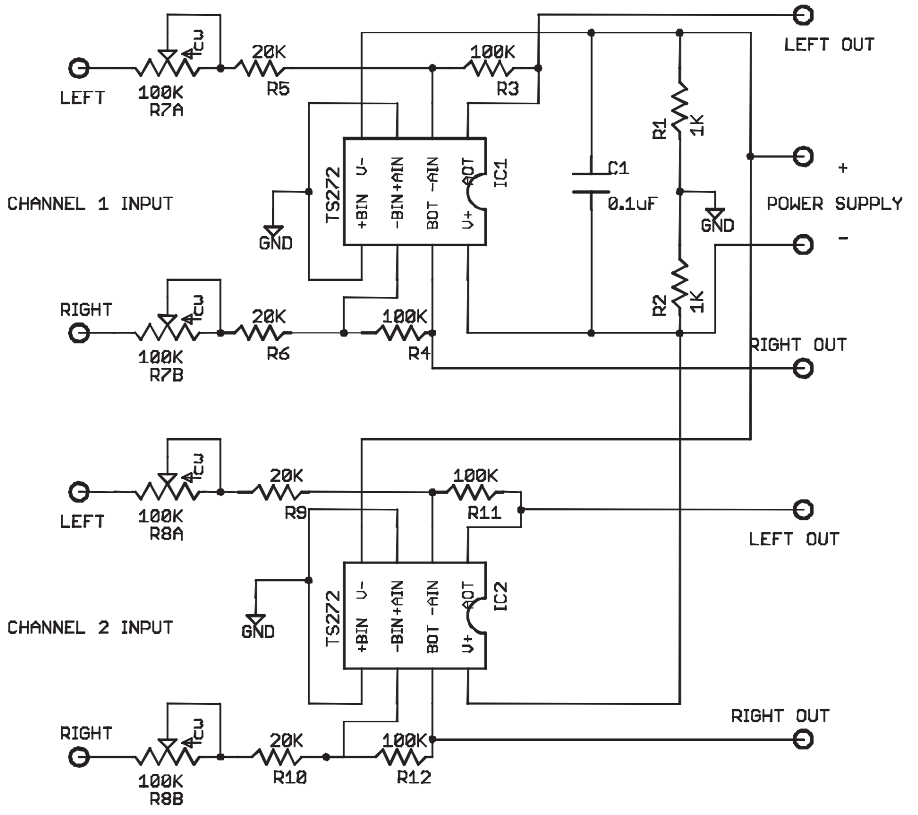
FLY ZAPPER

Q In the September '07 issue (page 30, Figure 4), I am interested in the fly zapper schematic. I have a raccoon tearing up our trash even though it is heavily secure. The coon is smart, big, and strong. Here's my thought — I do know a little about auto ignition and for the coil to output a good strong spark, it needs the correct ignition cap. Cap needs to be around 0.06 µF, but that depends on coil make. I have two coils for old VW Beatles without the caps and the local auto supply store (Pep Boys) wants an arm and a leg for the caps.

Also, for me to use your circuit I would need it to fire about 2X per second. I'll call it RussKin's Critter Getter. Any ideas on that? I'll bet that arm and leg that many people have the same problem with critters!

— Bob Jay (long-time subscriber)

A I can help you with the cap: 0.068 µF from Mouser, 72 cents, part number 5989-1KV.068-F. You can connect the cap across the coil primary and eliminate R1 and D1. To make the 555 run at 2 Hz, change R2 to 1.2K and R3 to 3.3 meg. Use C2 = 0.1 µF, Mouser part number 5989-250V.1-F.



PARTS LIST – MOUSER PART NUMBERS

PART	DESCRIPTION	PART NUMBER	PRICE EA
R1, R2	1K, 1/4W, 5%	271-1K-RC	0.90/10
R3, R4, R11, R12	100K, 1/4W, 5%	271-100K-RC	0.90/10
R5, R6, R9, R10	20K, 1/4W, 5%	271-20K-RC	0.90/10
R7, R8	DUAL 100K POT	313-2420F-100K	2.73
C1	0.1uF, 50V, 20% CERAMIC OR FILM	581-BQ014D0104J	0.12
IC1, IC2	DUAL OP AMP, CMOS	511-TS272CN	0.90
RCA JACKS (4 PAIR)		162-5122	1.13
POWER JACK (2.1 X 5.5 MM)		163-4302-EX	1.38
WALLWART, 12VDC REGULATED		802-STA-300R	13.94

■ FIGURE 3

VACUUM TUBE EQUIVALENT CIRCUIT

Q I have a circuit that I got from a magazine (transistor), but I wonder if I could convert it to tubes. I know tubes are old technology, but I like them. My endeavor was the circuit in Figure 4 — an OTL tube circuit. I had to make some compromises but I wonder if this scheme would work? The first tube is a pentode and a triode in one. The other tubes are power pentodes. I'm not sure if the biasing is right. I do know the transistor circuit says that the 680K R2 is adjusted to bring Q4, Q5 emitters to half the supply voltage. Is this tube circuit practical? One thing I know, the speaker will have to be higher impedance.

— Craig Kendrick Sellen
Carbondale, PA

A DC coupled tube circuits are difficult. Tektronix used to do it using NE-2 neon bulbs for level shifting. But let me list the problems with the tube circuit:

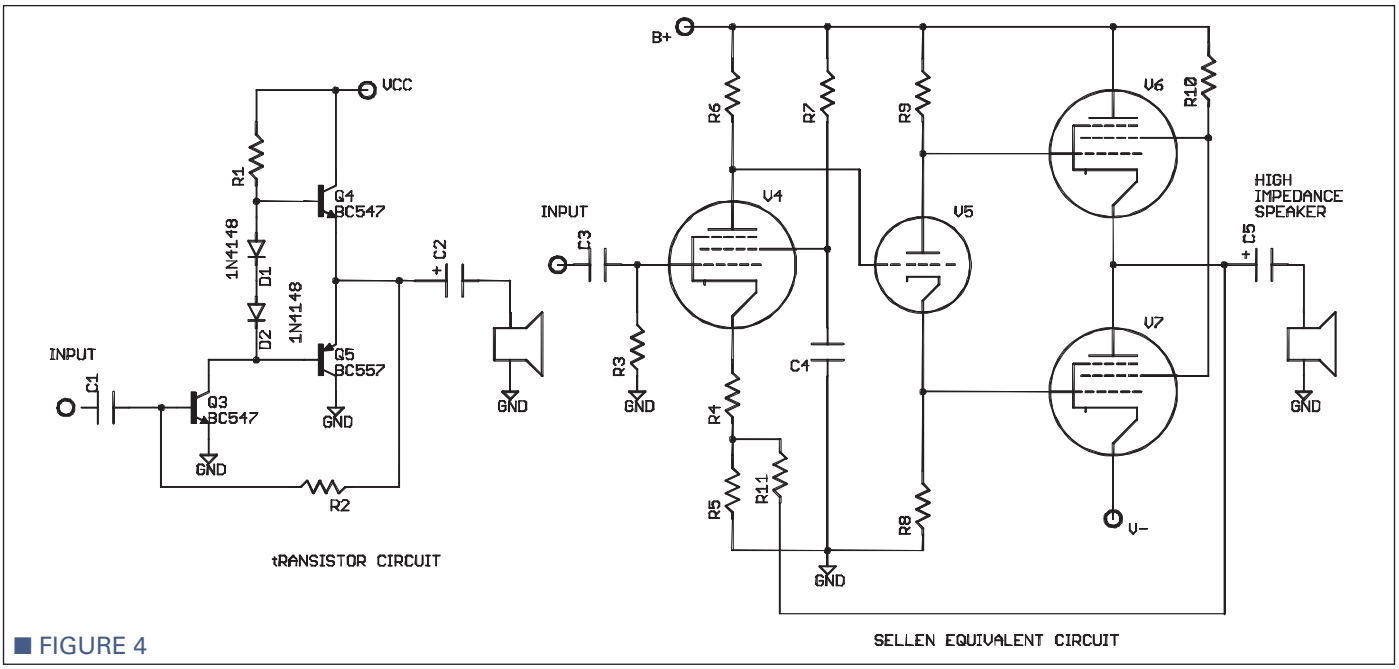
1) There is no tube equivalent for a PNP transistor. The cascode circuit will have low impedance pulling up and high impedance pulling down. That will not be a problem if the speaker impedance is high enough; but high impedance implies low power, and I don't know where you would find such a speaker.

2) With the cathodes at different potentials, you can't connect the screens together.

3) With V5 cathode near ground and V7 cathode at –V, V7 will be saturated. R8 should return to –V and V7 needs a resistor in series with the cathode to limit the current.

4) The connection between V4 plate and V5 grid is the place to put the NE-2 neon to bring the grid down close to –V.

Enough of the critique; vacuum

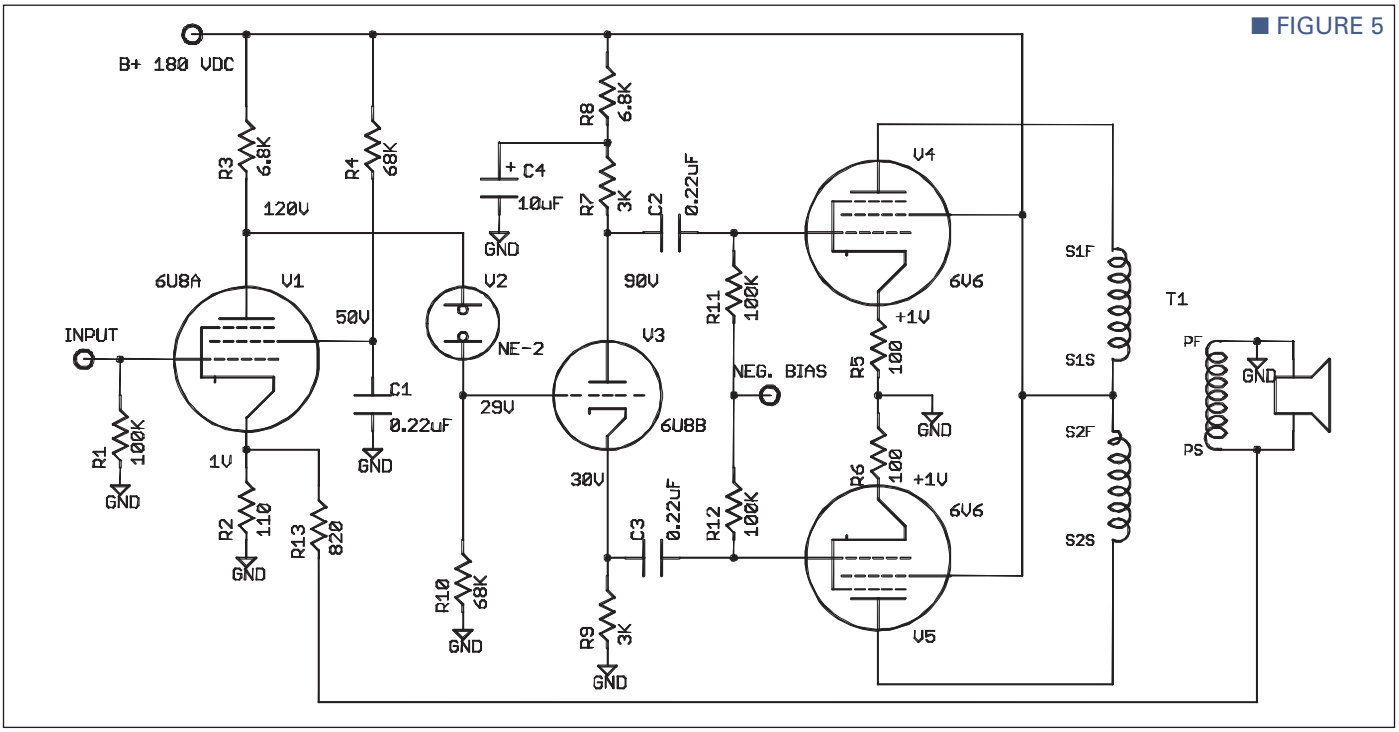


■ FIGURE 4

tubes should be operated push-pull, class AB, for reasonable power output and low distortion. I have modified your design in Figure 5. The final stage is AC coupled because there is no point in maintaining DC coupling, and it would be difficult. The first stage gain is about 60 (6.8K/110), but the second stage is just a phase splitter — it has no gain. You will need a preamp to get the maximum power output of seven watts. The bias current in the final stage is arbitrary; I chose 10 mA, so you would adjust the negative bias to obtain one volt DC at each cathode. Matched 6V6 tubes will be necessary. According to my tube manual, the output transformer should be 10KCT: eight ohms. I have labeled the schematic with the expected voltages and currents. If you build it, let me know how it works!

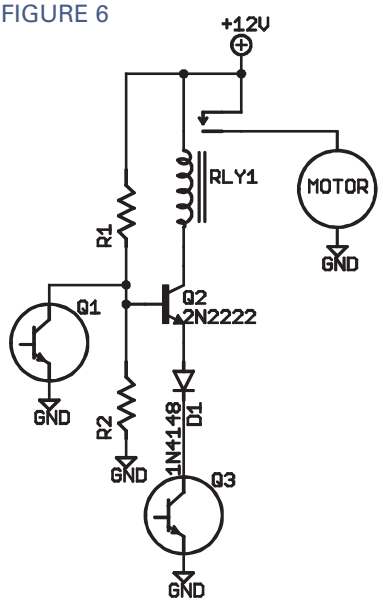
800 MHZ BUSINESS BAND COMMUNICATION

Q Can you tell me where I might get a book on FM communication decoding and encoding? Or, maybe at least a schematic? If it matters, it's for the 800 MHz business band FM. I have been monitoring the band for 4+ years now — just a hobby.



■ FIGURE 5

■ FIGURE 6



So, if you know where I might buy such a book, I would appreciate it.

— George Gunter USN (Ret.)

A I know nothing about this but if the signal is not clear voice, it may be frequency hopping spread spectrum. I don't think a schematic is applicable in this case. I found a few books at Barnes & Noble that may be of interest: *Spread Spectrum in Communication*, ISBN-13: 9780863410345; *Principles of Spread Spectrum Communication*, ISBN-13:9780201633740; and *Crypto: How the Code Rebels Beat the Government-Saving Privacy in the Digital Age*, ISBN-13: 9780786521951.

Another possibility is that the signal you are trying to receive may be digital voice. Cell phones operate in this band and I believe most, if not all, are now digital voice. If that is the case, this book may be helpful: *Telecommunications and Data Communications Handbook*, ISBN-13: 9780470041413.

TOOL SETTER REVISITED

Q I require a little more help with the Tool Setter circuit you designed for my milling machine (May '08, page 25). I had to reverse the contact logic in the milling machine so that my touch probe would work correctly. Because of this change, your original schematic for the Tool Setter will no longer work. Do you think you could take a second look at this circuit for me? Here are the new criteria for the Tool Setter:

1) The circuit is now normally closed (NC) and must open when a tool touches the top plate.

2) The secondary part of the circuit needs to be isolated from the frame of the milling machine.

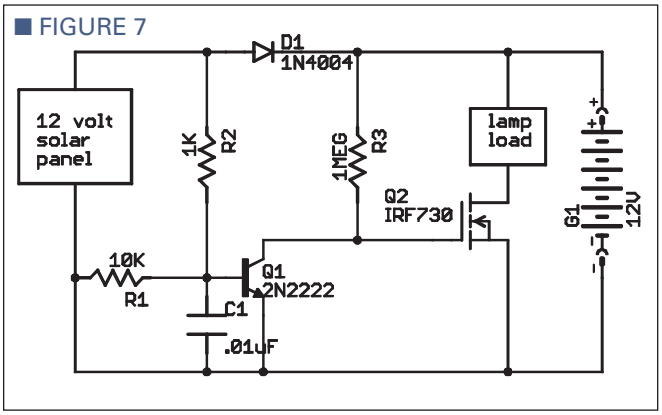
3) We can still use a battery to power the primary circuit.

4) I still would like an LED to come on when a tool touches the top plate.

— Bill Blackburn

A The solution is simple: just replace the HSR312 solid-state relay with the normally closed G3VM-353A, Mouser part number 653-G3VM-353A.

■ FIGURE 7



SOLAR TRACKER

Q I have three questions:

1) I am in need of a simple solar tracker schematic. Some years ago, T. J. Byers sent me one that for some reason, I can't get to work (Figure 6). I have changed components many times. I wired the two pin photo transistors both ways (no pin info); maybe you can supply that info for me — which is the collector, the longer lead or the shorter one? I've been working with the schematic over the years and like it for its simplicity but can't seem to make it work. What do I do to get this circuit to work? In theory, it sounds good. Could there be an error in this circuit? I recently used a Darlington transistor in place of the 2N2222 transistor; same results, it still doesn't work. What do I try next? I won't give up after so many years of trying.

2) Figure 7 is an automatic solar charger that turns on my solar lights all around my house. While experimenting with different MOSFETs, I find that the lights go on when it is still reasonably light outside due to the internal resistance of the MOSFET. I have not tried changing the voltage divider resistors, especially the 1K resistor, R2. Normally, it would be a simple task to just try changing the value of the resistor but unfortunately, the control box housing for the circuit is mounted in a difficult place. That is why I am asking your opinion on this particular circuit.

3) Do you have any simple solar circuits that charge a battery during the day then at night switch on the outside lights? I am now using some super bright 39 cluster LEDs which operate on 12 volts DC.

— Antonio J. Anzevino

A 1) There are no specs for the RadioShack photo transistor, so there is no way to know if it should work or not. I suspect that if you buy enough of them, you will find a pair that work. BTW, the shorter lead of the photo transistor is the collector.

Instead of a photo transistor, try using a CdS photo resistor, RadioShack No. 276-1657. There are five in the package so you should find two that will work. It may work without modification, but if you make

R1 a 500K pot (rheostat), you can adjust it such that the motor starts running when Q1 is partially shaded.

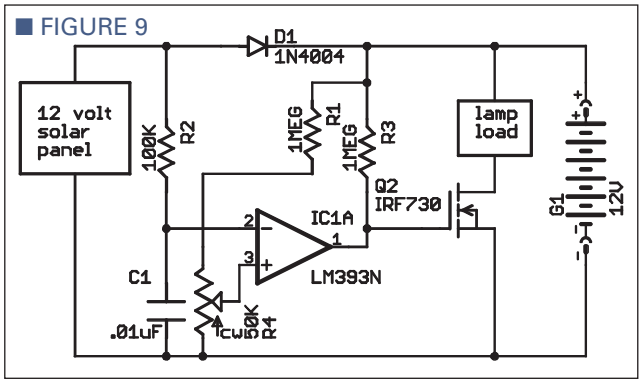
The way the circuit works is this: Q3 is the daylight/dark detector. In daylight, the photo transistor (and CdS cell) is low resistance, which allows the motor to run. Q1 is shaded by an east-west wall for the elevation servo and by a north-south wall for the azimuth servo. When Q1 is shaded, the base of Q2 is raised which closes the relay and starts the motor running.

When sunlight falls on Q1, the base is pulled down and the motor stops. You will want a way to return the servos to the starting position, ready for the next day.

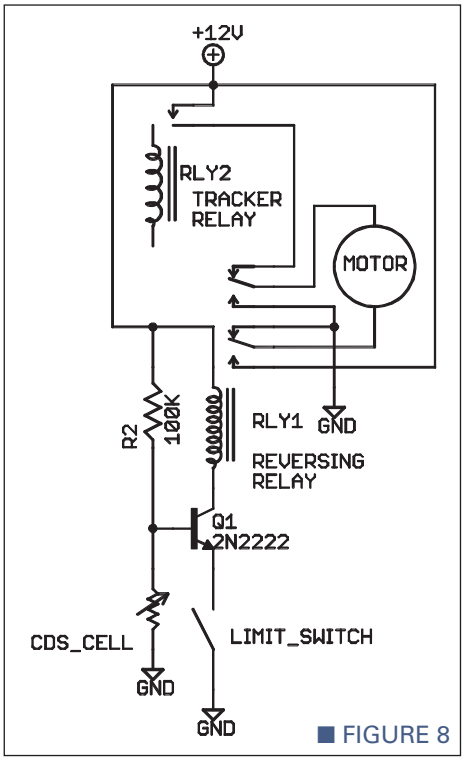
An alarm clock could be used for that or, another CdS cell as in Figure 8. When it is dark, the transistor is energized, causing the motor to run backwards until the tracker hits the normally closed limit switch, which opens the circuit.

2) It is not the MOSFET resistance that determines when the lights come on, it is the voltage output of the solar panel. The turn-on voltage of the FET and the value of R2 has a minor effect on when the lights come on, but when the 12 volt solar panel output gets down to 0.6 volts, it should be quite dark. You can gain some by removing R1 but that is only 50 millivolts difference, again minor. Bottom line, there is not much that can be done to vary the light level that determines when the lights come on.

■ FIGURE 9



3) Changing Q1 to a comparator as in Figure 9 will provide the variability that you want. The threshold can be adjusted all the way to zero; in which case, the lights may never come on.



■ FIGURE 8

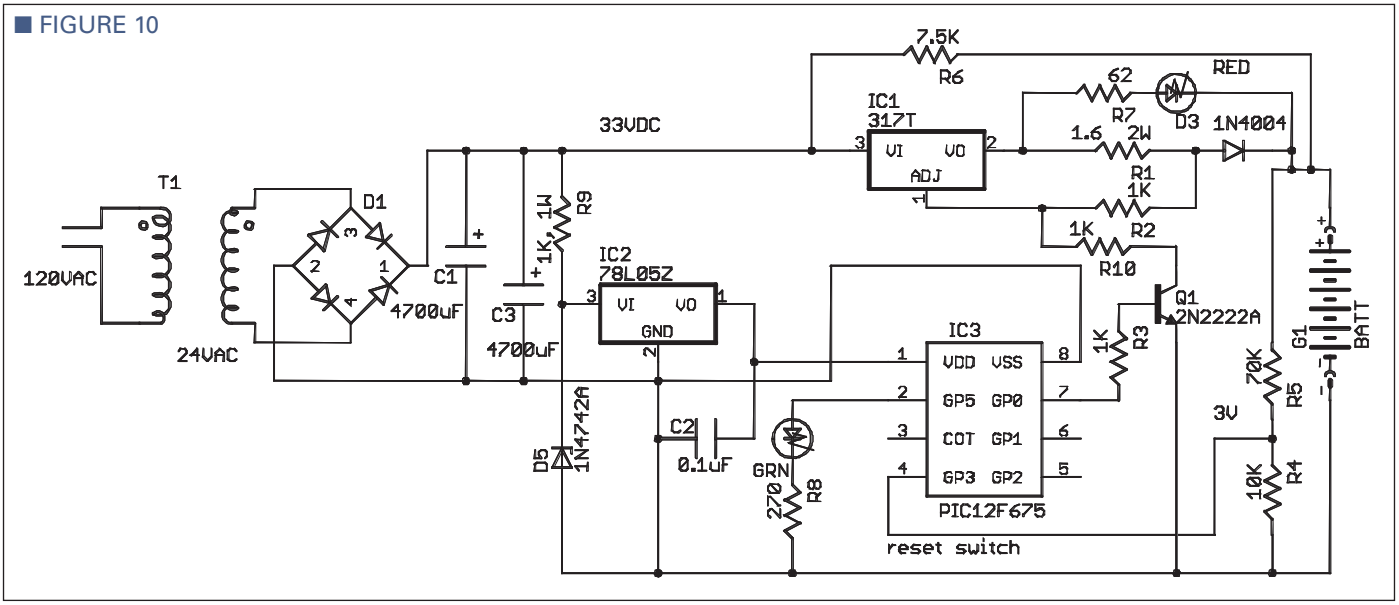
NIMH BATTERY CHARGER

Q In the *N&V* July '07 Q&A column, you provided a PIC-based charger circuit for NiMH batteries consisting of up to 10 cells.

What limits the charger to this maximum number of cells? If I use a power supply with more than 20 volts, can I use this to charge greater numbers of cells?Per your description, I would change the charge current by a bit because new cell capacities are always being introduced and, of course, the sense voltage divider (R4, R5) would also need adjusting.

— Dave Carpenter

■ FIGURE 10



MAILBAG

Dear Russell,

In your answer to Geff Waite, I was glad to see your comment about the capacitor ripple current. Too often it is ignored. Unfortunately, it isn't quite as simple as you said. Different manufacturers, different series from the same manufacturer, and different cap values have different ripple current ratings. A few of the caps in the Mouser and Digi-Key catalogs have ripple current ratings. Most manufacturers' capacitor datasheets give the ripple current ratings. The quickest way to get the datasheets is to do an Internet search of the manufacturer's name and the capacitor series ID.

A quick look at the Mouser catalog gives some examples. For Xicon snap-mount, series LS, a 25 volt 4,700 µF cap is rated at 2.31 amps ripple current, while a 63 volt 4,700 µF cap is rated at 3.49 amps, and a 200 volt, 2,200 µF is rated at 5 amps! For nearly every cap series of every manufacturer, the ripple current goes up (and the ESR goes down) as the voltage rating is increased. Because of this, I try to stay away from low voltage caps, even in low voltage circuits. (This difference may be primarily from the can size; a larger can has better heat dissipation.)

For the 10 amp DC output of Mr. Waites' power supply, the ripple current would be 13 to 15 amps, depending on the resistance of the transformer windings and other factors (including the effective series resistance of the AC power line). For any power supply, if the caps seem to run warm, the ripple current may be too high. The easiest cure is to parallel more caps. The actual ripple current can be measured fairly easily. Connect a 0.1 ohm or smaller, 1%, three watt resistor (available from Mouser) in series with the cap, measure the voltage across the resistor with a true RMS meter, and calculate the current.

We might also mention the current rating of the transformer. There has been some discussion of this recently. For a bridge rectifier and 10 amps DC output, the transformer should be rated at 16 to 18 amps RMS (depending on which transformer manufacturer's guidelines you follow). And there's always the question, build or buy? Marlin P. Jones and Assoc. (**www.mpja.com**) sells a 24 volt 12.5 amp switching power supply (no. 16489-PS) for $97.

— Bill Stiles

Thanks for the feedback, Bill. I had not noticed that current rating goes up with voltage rating. Good info.

Dear Russell,

In response to your statement that "There is no quality of sound advantage in hybrid digital; analog FM stations already transmit more bandwidth than most people can hear and with low distortion," I should like to invite you to my home in a northern suburb of New York City where I, a classical musician, can find virtually the only listenable FM by pointing my 14-element beam at lower Connecticut. There I will demonstrate what happens when I tune WSHU at 91.1 and wait for my Sangean HDT-1 tuner to recognize the signal as digital, at which point the background noise drops out, the separation increases, and all I hear is music.

I am now waiting for the one "classical" station from New York City to go digital so I can receive it without the multipath distortion which makes it virtually unusable.

— Robert Voss

Not having had the experience of multipath distortion with FM radio, I was not aware that it was a problem. I get excellent reception of classical music from WCRB, Boston at 99.5, 50 miles away. I believe WCRB is hybrid digital also; you should be able to receive it.

A The schematic (Figure 10) is modified to charge 20 cells. I added R9 and D5 because 33 volts exceeds the input rating of the 78L05. I also added R10 to reduce the input to ground (ADJ) voltage. R10 is not strictly needed because the 317 is rated 40 volts input, but it shows what needs to be done if the voltage goes much higher. I changed the voltage divider, R4 and R5, to provide three volts max to the A/D. The A/D voltage only has to stay between 1V and 4V as the batteries charge. **NV**

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- USB front panel host port for USB Flash drives and USB device interface standard
- Advanced features include digital filter with adjustable limits, mask testing, and waveform recorder/replay mode
- Cursors with readouts
- 24 automatic measurements
- FFT standard plus three additional math functions
- Extensive triggering capabilities including pulse width and line-selectable video trigger
- Multiple language interface
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PROPELLER PROTO BOARD USB TEXT

Parallax, Inc., introduces the new Propeller Proto Board with USB.

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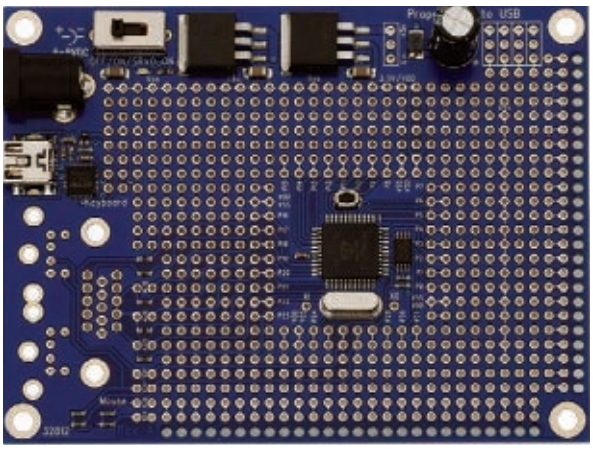

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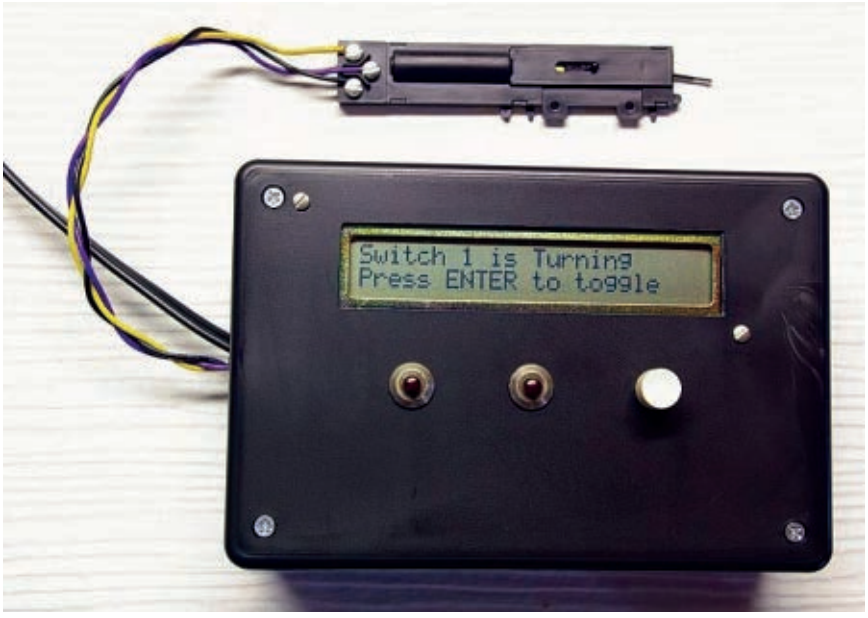
MODEL TRAIN SWITCH CONTROL VIA PC OR PIC

BY DAN GRAVATT



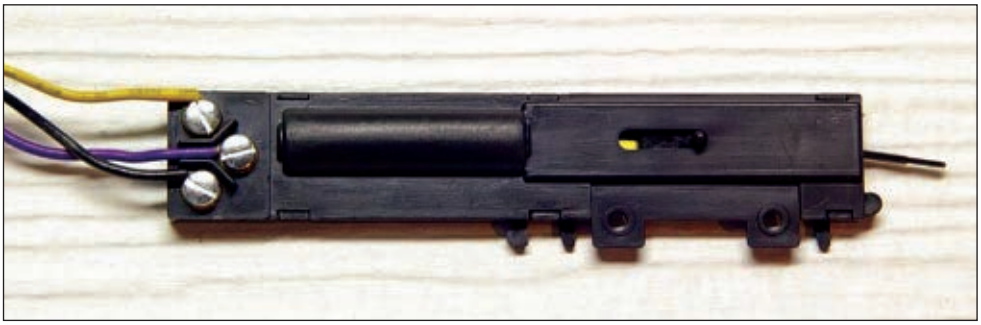
This is a project I wanted to do many years ago when I was spending a lot of time and money on my model railroad. I was disappointed by the big, clunky electrical controllers which operated the track switches, and I wanted to have something smaller and more elegant to do the job. A computer control system would have been ideal, but I never got around to designing one. Many years and several designs later, I have come up with two versions of the control system: one PC-based and one PIC-based.

Both designs work on the same basic principles. The PC-based system has many possibilities for displaying track switch status, at the expense of needing a dedicated computer at your model railroad control station. The PIC-based system is a stand-alone direct replacement for the manual electrical controllers and has a simple three-button user interface.

There are other control systems commercially available for track switch control, mostly based on the Digital Command and Control (DCC) standard. DCC was originally designed to control model locomotives by sending power and data through the tracks, allowing multiple DCC-enabled locomotives on the same track to do different things. Add-on modules for DCC are available to control track switches, but they are fairly expensive and won't work without a master DCC system. My control system will work just fine on either DCC or non-DCC model railroads as it does not depend on any other hardware.

Anatomy of a Track Switch

The most common model railroad track switches — often called snap switches — are electromagnetically actuated by two solenoid coils: one moving the track to the "straight ahead" position and the other for the "turn" position (Figure 1). Reversing the polarity



■ FIGURE 1. Track switch solenoid. When attached to the railroad track, the lever on the end of the solenoid moves the track section back and forth.

of the voltage on a coil does not change the track switch's position and, in fact, the manual electrical controllers that come with the track switches use low-voltage AC. A momentary current pulse is applied to one or the other of the coils to make the track switch change position. Unlike an electromechanical relay, no current is required to hold the track switch in position; continuously energizing either coil will cause it to burn out.

A second type of track switch — known as a slow-motion or "tortoise" switch — uses a small DC motor and reduction gears to gradually move the track switch from one position to the other. This type of switch is favored by modeler railroaders who want to more realistically simulate the movement of a real railroad switch mechanism. Tortoise track switches also contain electrical limit switches to provide feedback on the track position without having to look at it — a good thing when your model railroad is large.

The control system I describe here is designed to operate snap-type track switches. However, most of the circuitry and code could also be applied to operating tortoise switches, with some modifications to the power output driver stages.

PC-Based Control System

The PC-based control system takes advantage of the ubiquitous eight-bit parallel port, which is easily interfaced to external TTL circuitry to operate the track switches. Any laptop or desktop PC will suffice for this application, as long as its operating system will allow you to directly access the printer port LPT1. Since I am not much of a programmer, the user interface is strictly bare-bones, but it could be replaced by any custom graphical interface you would care to write, as long as it follows the underlying principles for interfacing with the external circuitry.

PC Software Development

The software for this project (Listing 1, also available on the *Nuts & Volts* website at **www.nutsvolts.com**) is written in QuickBASIC, mostly because I never learned any other PC programming languages. You may have a copy of QuickBASIC on CD and don't even know it; it can be found on the Windows 98SE installation disk in the directory D:\tools\oldmsdos. Running QuickBASIC in a DOS window under Windows 98SE, I had no problem writing data to the printer port LPT1 using the command "OUT &h378" where "378" is the hexadecimal address of LPT1. If you use other programming environments or operating systems, make sure they allow you to write data directly to LPT1 without interference.

The software performs three tasks. First, after prompting you to power-up the circuit, all track switches are reset to a known position — I arbitrarily chose "straight ahead." This is done one at a time to avoid overloading the power supply for the track switches. After this is finished, a table showing the track switch positions is displayed along with a prompt to select a track switch to be moved. Any time a track switch is selected, one byte of data is sent through LPT1 to the external decoder/driver circuit to energize the selected coil, followed by a second byte of data to de-energize that coil. The table of track switch positions is then updated, and the software is ready to move another track switch.

Listing 1

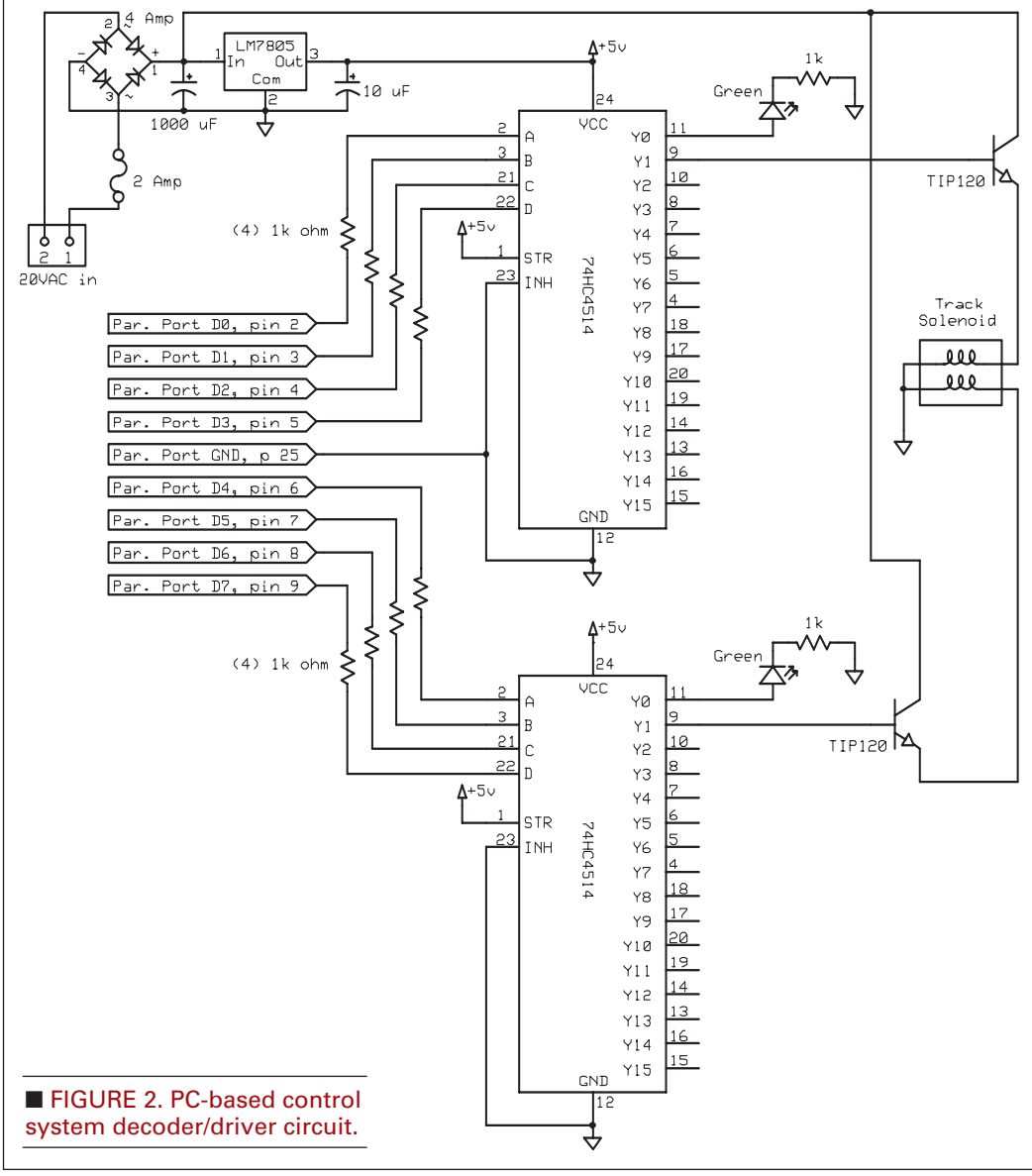
```
REM toggles model railroad switches using two 74HC4514 4-to-16 decoders on LPT1

DIM switch(1 to 15) AS INTEGER
OUT &H378, 0
CLS: INPUT "Power up the switch controller, then press enter", null
PRINT: PRINT "Resetting switches, please wait..."
FOR x = 1 to 15
OUT &H378, x
SLEEP 1
OUT &H378, 0
switch(x) = 0
NEXT x

Main:
CLS: PRINT "Model Train Switch Control v1.0"
PRINT
PRINT "Switch Position Status:"
PRINT
FOR x = 1 to 15
PRINT "Switch "; x; " is ";
IF switch(x) = 0 THEN PRINT "Straight" ELSE PRINT "Turning"
NEXT x
PRINT
INPUT "Select switch (1 through 15) to move: ", move

IF switch(move) = 0 THEN
OUT &H378, move
switch(move) = 1
ELSE
OUT &H378, move * 16
switch(move) = 0
END IF

SLEEP 1
OUT &H378, 0
GOTO Main
```

PC Circuit Theory

The decoder/driver circuit for the track switches is very straightforward, consisting primarily of two 74HC4514 4 to 16 decoders and 30 TIP120 NPN Darlington power transistors (Figure 2). There are two nearly identical halves of the circuit: one for driving all the "straight ahead" coils in the track switches; and one for driving all the "turn" coils. (Note that only one of the 15 track switch driver circuits is shown in Figure 2 for clarity.) The four low bits of the parallel port feed one decoder's inputs, and the four high bits feed the other's. The "0" output of the decoders is not used since — for programming simplicity — the decoder's Inhibit input is not controlled by the parallel port. Thus, one of the decoder outputs must be active at all times and, as stated before, the coils will burn out if continuously energized.

The software's "ready state" causes the "0" decoder outputs to go high, and they are used to drive LEDs indicating the circuit status — green for ready and off when active. Current limiting resistors are used between the parallel port and the decoder inputs to help isolate the parallel port from the external circuitry. I found that the current needed to drive the power transistors was less than one milliamp — well within the output drive specification for HC TTL devices, so I omitted any current limiting resistors between the decoders and power transistors.

Model railroads often include track switches at both ends of a track segment (such as a siding) that are operated in parallel to allow a train to access that track segment. The current rating of the TIP120 is more than adequate to drive a pair of track switches in parallel, as each coil typically draws around 1A at 12 volts DC (although this varies by manufacturer; I tested the circuit using an Atlas-brand track switch). The TIP120 has a built-in reverse-protection diode to absorb the voltage spikes generated as the coils de-energize, protecting the transistors and decoders from damage.



■ FIGURE 2. PC-based control system decoder/driver circuit.

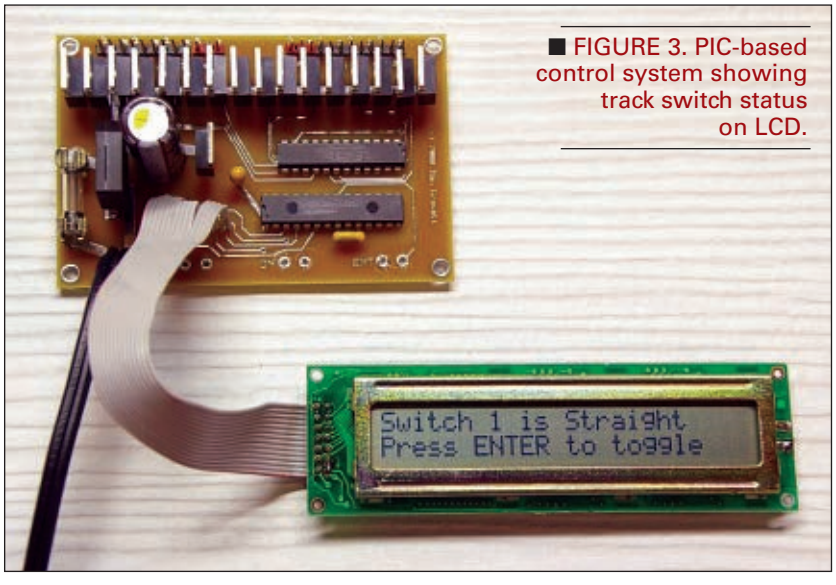
The power supply portion of the circuit is designed to be operated from the 20 VAC accessory supply available on most model railroad power packs. Thus, no separate power supply is necessary, and the DC voltage available from the bridge rectifier (around 28 VDC) is more than sufficient to operate the track switch solenoids. Current draw from the 7805 voltage regulator is minimal, so no heatsink is required. The low duty cycle of the TIP120 transistors means they do not need heatsinks either.

Circuit layout and construction is not critical, though I would not recommend using point-to-point wiring. One word of caution is in order on the circuit's operation: Make sure the circuit is connected to the PC's parallel port and the software is running before applying power to the circuit. This ensures

Listing 2

```
' Toggles model railroad switches using PIC16F876 and one 74HC4514 4-16 decoder
' HD44780-based LCD connects as follows:
' DB4-PortA.0, DB5-PortA.1, DB6-PortA.2, DB7-PortA.3, RS-PortA.4
' E-PortB.3, RW-Ground, DB0-3 No connect
' PortC.0-3 to decoder
' PortB.4 to INHIBIT pin on 74HC4514 so all 16 outputs can be used

switch var bit[8]       ' Defined as 0 through 7!
switchnum var byte
TRISC = 0
high PortB.4
poke 129, 127           ' Turns on PortB's weak pullup resistors

for switchnum = 0 to 7  ' Loop to reset track switch positions
PORTC = switchnum
switch(switchnum) = 0
pulsout PortB.4, 40000  ' 0.4s low pulse to activate decoder
next switchnum
switchnum = 0

Main:
if switch(switchnum) = 0 then LCDOUT $fe, 2, "Switch ", dec switchnum + 1, " is Straight ", $fe, $c0, "Press ENTER
to toggle    "
if switch(switchnum) = 1 then LCDOUT $fe, 2, "Switch ", dec switchnum + 1, " is Turning  ", $fe, $c0, "Press
ENTER to toggle    "
pause 500
select case PORTB
     case 243           ' up button on PortB.2, low when pressed
          switchnum = switchnum + 1
          if switchnum > 7 then switchnum = 0
     case 245           ' down button on PortB.1, low when pressed
          switchnum = switchnum - 1
          if switchnum > 8 then switchnum = 7
     case 246           ' enter button on PortB.0, low when pressed
          if switch(switchnum) = 0 then
          switch(switchnum) = 1
          PORTC = switchnum
          else
          switch(switchnum) = 0
          PORTC = switchnum + 8
          endif
          pulsout PortB.4, 40000
end select
goto main
```

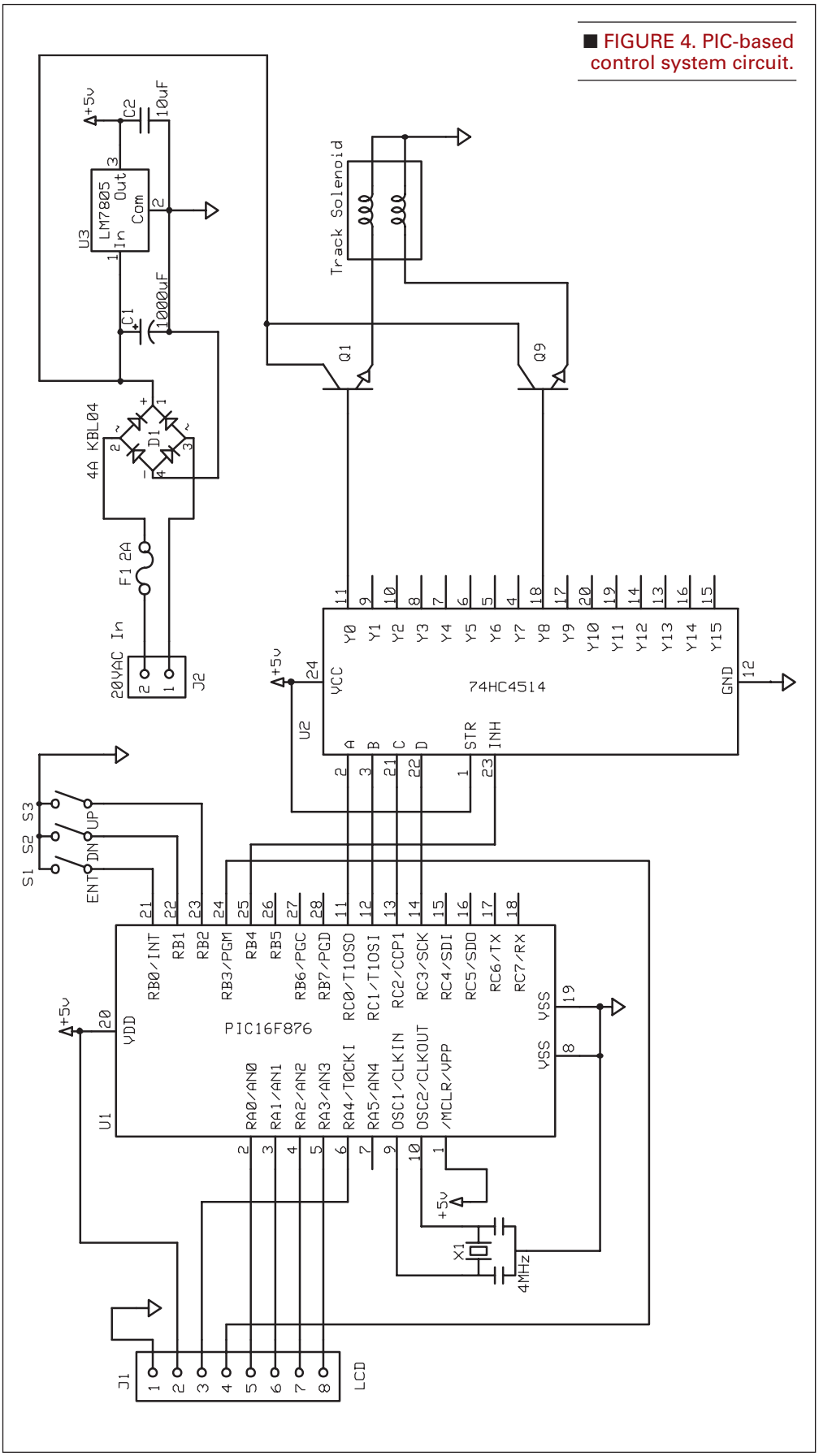
that the "0" outputs of the 74HC4514s will be active, and there will be no unpredictable track switch movements. If you apply power without connecting to the parallel port, the decoder inputs will assume random states, leading to randomly selected outputs. If you apply power while your computer is booting up or running other software, the states of the parallel port data lines are unknown and most likely incompatible with proper circuit operation. Just for fun, try connecting some LEDs to the parallel port's data lines (use current limiting resistors) and watch what they do while your computer boots — you'll see what I mean.



■ FIGURE 3. PIC-based control system showing track switch status on LCD.

PIC-Based Control System

Although the PC-based system was easy to



■ FIGURE 4. PIC-based control system circuit.

design and offers a lot of flexibility in the user interface, it wasn't really true to my original intent to create a drop-in replacement for the multitude of electrical switch boxes typically used to control track switches. I decided to take the decoder-driver circuit from the PC-based system and add a PIC microcontroller and liquid crystal display (LCD) to make a self-contained controller (Figure 3). The controller described here operates eight track switches and can easily be expanded to control 16 using the same basic operating principles.

PIC Software Development

The popular Microchip PIC16F8761 forms the heart of this project, and flowing through that heart is the code in Listing 2 (file available on the *Nuts & Volts* website). This code performs the same three main tasks that the PC-based software performs and, in addition, monitors three switch inputs and drives the two-line by 24-character parallel-mode LCD.

The three pushbutton switches making up the user interface include an up button to increment the track switch number, a down button to decrement it, and an enter button to move the selected track switch. All three buttons have a repeat action when held down, to scroll through the track switches or cause one switch to move repeatedly (not very useful, but fun to watch for a few seconds). The code determines which switch is pressed by checking the value of PORTB, which represents the state of all eight Port B I/O lines as one value. Pins PortB.5 through PortB.7 are unused and always high, while PortB.3 (the enable output for the LCD) is

PARTS LIST

PC-Based Control System:

ITEM	DIGI-KEY P/N (except for LCD)	QTY
❑ 74HC4514 four to 16 decoders	MM74HC4514N-ND	2
❑ TIP120 NPN Darlington power transistors	TIP120-ND	30
❑ 7805 Linear voltage regulator, TO-220 package	MC7805CT-BPMS-ND	1
❑ KBL04 four amp diode bridge	KBL04-E4/51GI-ND	1
❑ 1000 µF 50 volt electrolytic capacitor	P5186-ND	1
❑ 10 µF 50 volt electrolytic capacitor	P5178-ND	1
❑ Two amp fuse	F2705-ND with 3520K-ND clips	1
❑ 1K resistors	1.0KH-ND	10
❑ Green LEDs	511-1195-ND	2

PIC-Based Control System:

❑ Two-line by 24-character LCD	LCD107 or LCD113 (All Electronics; **www.allelectronics.com**)	1
❑ 74HC4514 four to16 decoder	MM74HC4514N-ND	1
❑ PIC16F876 microcontroller	PIC16F876A-I/SP-ND	1
❑ 4 MHz ceramic resonator with capacitors	X902-ND	1
❑ TIP120 NPN Darlington power transistors	TIP120-ND	16
❑ SPST PCB-mounted momentary switches	P12223SCT-ND	3
❑ 7805 Linear voltage regulator, TO-220 package	MC7805CT-BPMS-ND	1
❑ KBL04 four amp diode bridge	KBL04-E4/51GI-ND	1
❑ 1000 µF 50 volt electrolytic capacitor	P5186-ND	1
❑ 10 µF 50 volt electrolytic capacitor	P5178-ND	1
❑ Two amp fuse	F2705-ND with 3520K-ND clips	1

low and PortB.4 (the inhibit output for the 74HC4514 decoder) is high when the state of PORTB is being read.

Valid values of PORTB for the SELECT CASE command correspond to PortB.3 and either PortB.0, PortB.1, or PortB.2 being pulled low. Pressing more than one button at a time – which might lead to unpredictable track switch movements – yields an invalid value of PORTB which is ignored. To minimize the parts count, the internal Port B weak pull-ups are enabled, so no external pull-up resistors are needed for the three pushbutton switches.

The position status of each track switch is stored in an eight-bit array variable which is updated each time the enter button is pressed. The position status and/or selected switch number is updated on the display with each pass through the main program loop. The LCDOUT command from PICBASIC PRO is used to drive the LCD, which uses a standard HD44780 controller chip. All of PICBASIC PRO's default parameters and pin assignments for the LCDOUT command are used.

PIC Circuit Theory

The main difference between the decoder-driver portions of the PC-based and PIC-based circuits is the use of the Inhibit pin on the 74HC4514 in the PIC-based circuit (Figure 4). This allows all 16 outputs to be low at once, and thus they can all be used to control the track switch coils. Rather than have separate decoders for the straight and turn coils, outputs 0-7 drive the straight coils and outputs 8-15 drive the turn coils. When the enter button is pressed, the binary value of the track switch coil to be activated is placed on PortC.0-PortC.3, and a PULSOUT command on PortB.4 sends a 400 millisecond negative pulse to the 74HC4514's Inhibit pin which briefly enables the selected output. Adding a second 74HC4514 decoder with its inputs driven by PortC.4–PortC.7 and its Inhibit pin driven by PortB.5 allows up to 16 track switches to be controlled, with some minor changes to the code.

Wrap-Up

I hope that one of the approaches described here will inspire you to replace your old manual controllers with something more user-friendly. Or, for those not into model railroads, I encourage you to come up with other uses for the circuits and code described here. Send your results to *Nuts & Volts*. I'm sure the readers would enjoy them! **NV**

Contact the Author

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FOOTNOTE 1:
Programmed PIC16F876s are available from the author.

AUDIO SPECTRUM ANALYZER

BY LARRY CICCHINELLI

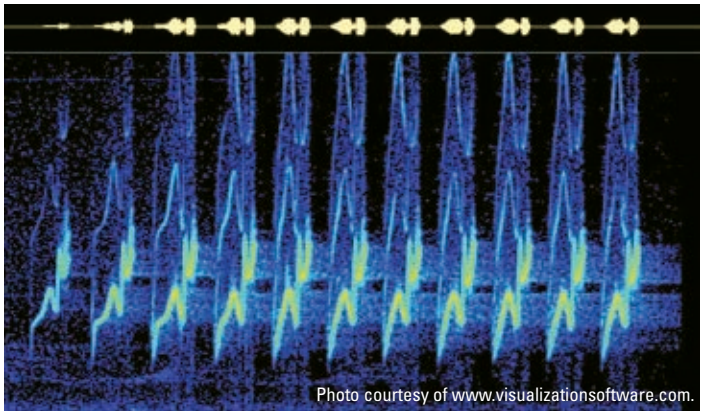


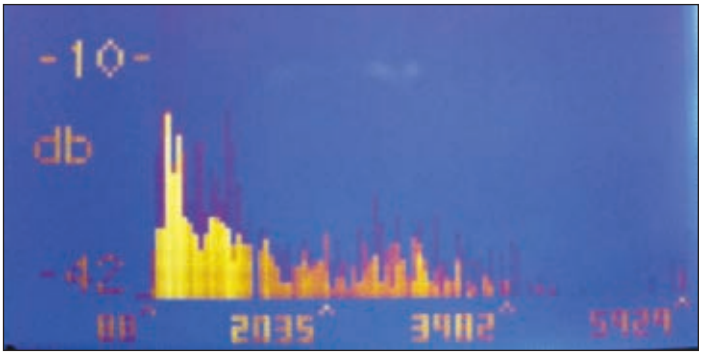
Photo courtesy of www.visualizationsoftware.com.

The device described in this article is a configurable audio spectrum analyzer. Many of you have probably seen spectrum analyzers on some higher-end audio equipment, as well as within the GUI of many audio deck programs on your PCs. The function of a spectrum analyzer is to view the frequency components of a signal. One way to state the difference between an oscilloscope and a spectrum analyzer is that with an oscilloscope, you see time domain presentations; with a spectrum analyzer, you see into the frequency domain.

When I first thought about this project, I simply wanted to see if I could do it. I had never worked with Fast Fourier Transforms (FFTs) before or developed an interface and software for a graphics LCD. It was a very interesting and rewarding experience! One of my primary uses for this device will be to monitor the output of a public address (PA) system I am responsible for. It lets me see if any frequencies are being over or under emphasized. I can also see the frequency of any feedback and then adjust the equalizer accordingly. Used in conjunction with my DDS (*N&V*, November '06), it can be used to determine the acoustic characteristics of a room or PA/recording system.

This unit has been designed to view audio signals up to about 20 kHz. The data is displayed on a graphics LCD with a pixel matrix of 64 x 128. It uses a microprocessor-based module with a clock speed of either 29.5 MHz or 59 MHz that enables a maximum display update rate of about 5 or 10 Hz. The audio processing circuit allows you to select one attenuation value or any combination of three gain values.

■ FFT analysis display of a complex audio signal.



The program uses several separate — but coordinating — files to complete the software for the system: the main program, a library for the LCD, and a library specifically for the menu functions. Provision has been made to allow the user to store up to 10 custom configurations. Since the source code is available, you can customize the program to meet your specific needs. To do this, you will need access to a development system for the microprocessor. If you do not want to incur the expense of a development system, I will be happy to program the microprocessor module for you if you send it to me with a SASE. (Contact me at k3pto@arrl.net)

Although the program uses the FFT, I will not be going into any details on how this works. There are good descriptions of this algorithm available on the web, as well

NOTE:
Circuit board artwork is available on the *Nuts & Volts* website at **www.nutsvolts.com**.

as others that transform between the time domain and the frequency domain. There is a good primer of the DFT in the October '07 issue of *Nuts & Volts*.

This device is relatively small, fitting into an enclosure of about 6.8" x 4.8" x 2.5", and is powered by a DC wall wart between 9V and 15V. Someone who is better at packaging than I am could probably fit it into a smaller enclosure. I tried a 4.5" square box but could not quite make it work.

The main thrust of this article is to describe each of the circuits, some of the software, and the construction of the system. Complete construction information, including the bill of materials (BOM), schematics, and printed circuit board (PCB) details can be found on my website at **WWW.QSL.NET/k3pto** under the heading "Audio FFT display." The source code for the main program and the libraries are also on my website, as well as at **www.nutsvolts.com**.

The three circuit boards embody of the following: power supply and processor; analog circuits; and the interface for the graphics LCD. I could have put the LCD interface on the same board as the processor but I decided to make it a separate board for two reasons: (1) it allows the LCD to be ported to other projects more easily; and (2) the board has very fine and closely spaced traces (.020" pitch). I felt it would be advantageous to have a separate board just in case the first assembly attempt fails. Then only this board would be affected — see the Construction Notes elsewhere in this article.

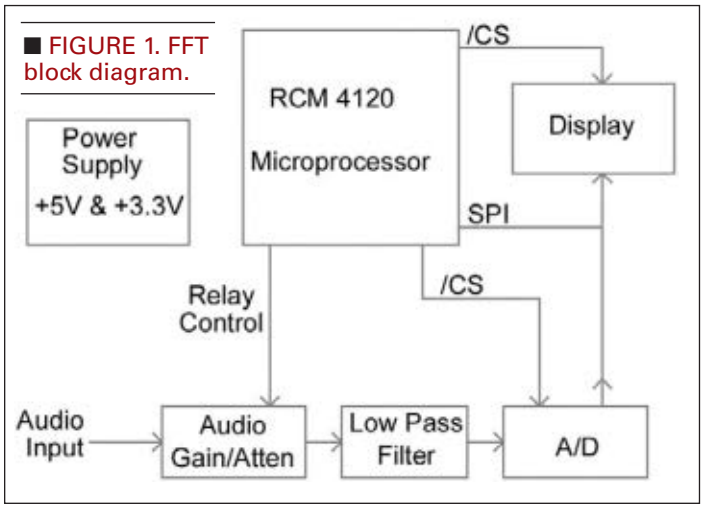
Figure 1 is a block diagram of the system. Note that the controlpath to the display and the ADC are over SPI (Synchronous Peripheral Interface). This is a serial communications protocol designed by Motorola in the 1960s. It is a popular method of enabling a microprocessor to communicate with peripheral devices, usually on the same circuit board. With SPI, you can control several devices connected to the controller via a serial bus that has the following signals: Clock, Data In, and Data Out. Each controlled device also requires a separate Chip Select signal.

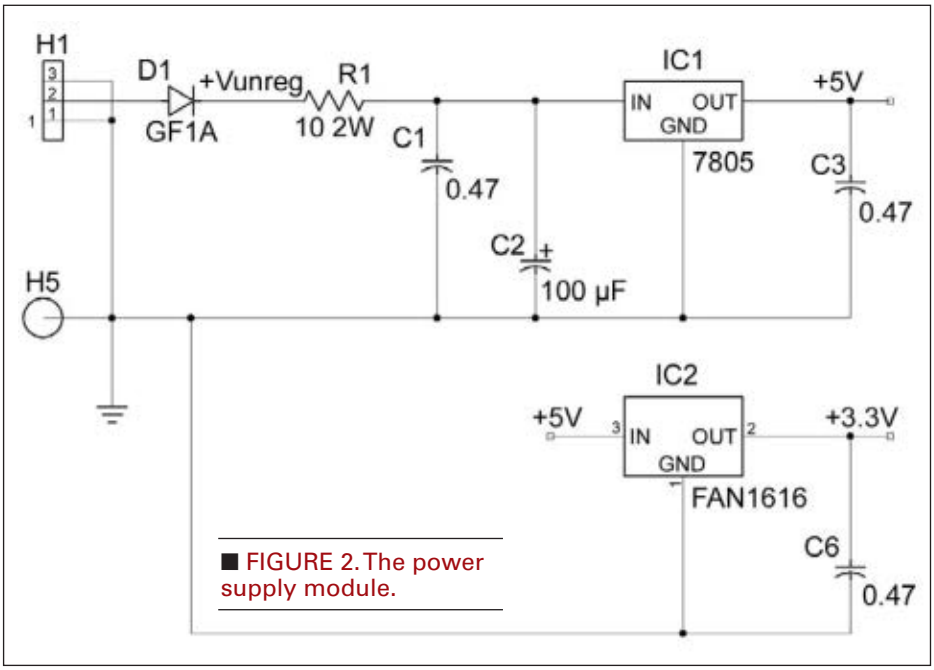
When implementing an SPI system with multiple devices, you need to make sure that the proper phase relationship (there are four possibilities) between the clock and the data is maintained for each device. In this system, both devices use the same clock to data phasing. One project I built (see *N&V* November '06) used two devices from the same manufacturer that had different clock to data phasing so I had to adjust the phase each time I initiated communications with one of them and then put it back when done.

The power supply (Figure 2) contains two series regulators: 5V and 3.3V. The 5V is used by the analog circuits and the 3.3V by the microprocessor and LCD. The output of the 5V regulator is also the source for the 3.3V regulator. The series resistor, R1, reduces the power dissipation of the 5V regulator. If you want to optimize the circuit a little, you can change the resistor based on the wall wart you use. The analog circuit current is about 20 mA (mostly due to the relay) and the 3.3V current is either 70 mA or 140 mA, depending on the processor board you are using. You have to have at least 7V on the input of the 5V regulator for proper operation. With a 10 ohm resistor, the voltage drop with 200 mA will be about 2V. So, a 9V wall wart is sufficient to power the unit that uses the faster processor. If you choose to use the slower processor, then a 20 ohm resistor will be a better choice. Be sure to get a resistor with the appropriate power rating.

There are two main functions the Input Amplifier/

■ FIGURE 1. FFT block diagram.





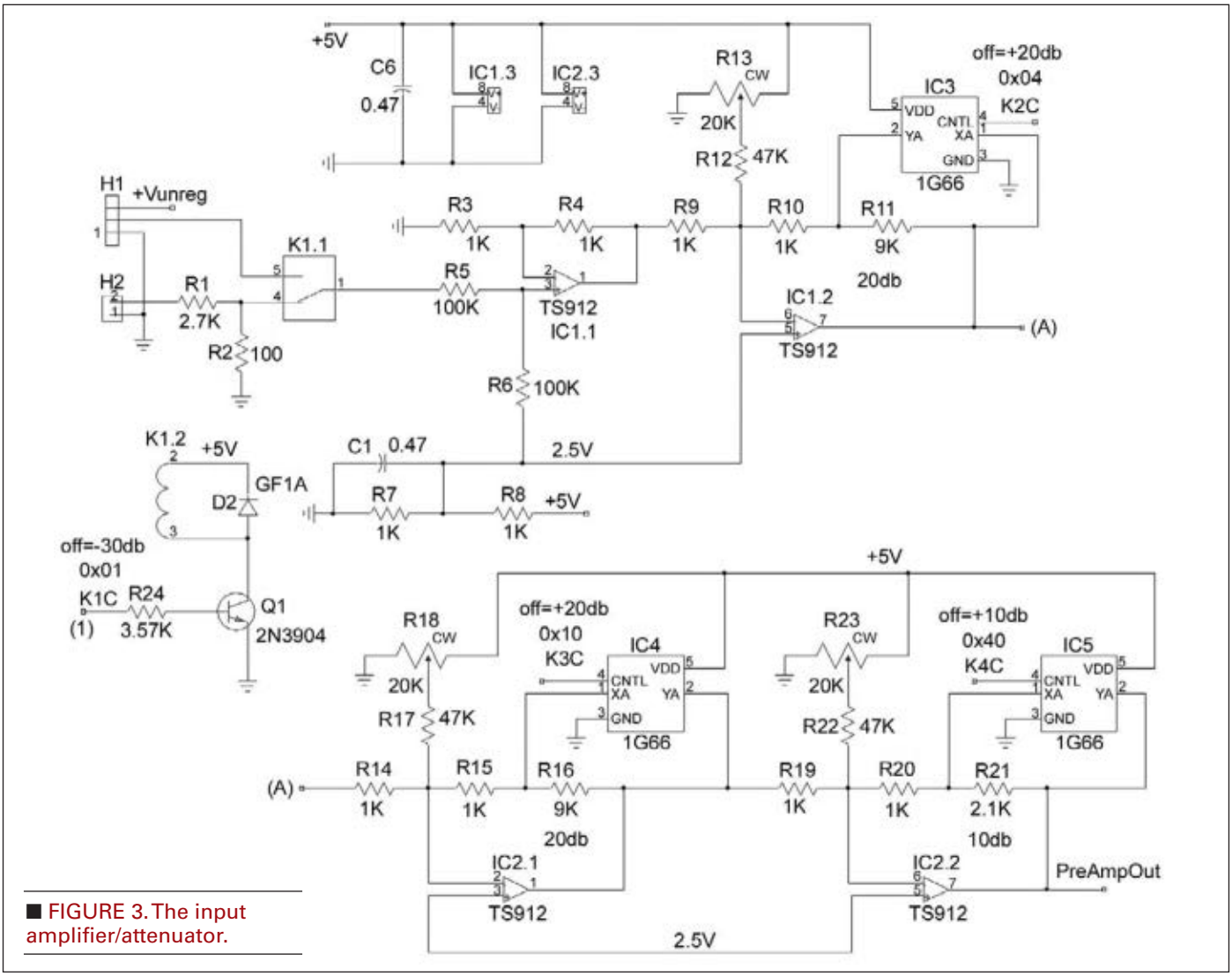
■ FIGURE 2. The power supply module.

Attenuator circuit (Figure 3) must perform: (1) give the input signal a fixed 2.5V offset; and (2) present an approximately 1 VRMS signal to the input of the ADC. The 2.5V offset is required because the op-amps and ADC are powered by a single supply (+5V) and will operate properly only with positive input signal voltages. This circuit allows the input voltage to be symmetrical around ground. Resistors R1 and R2 form a voltage divider that allows you to measure voltages greater than what can be sent through the op-amp circuits. The voltage applied to the input side of R5 needs to be symmetrical about ground and no larger than about 1 VRMS.

The circuit of IC1.1 gives the input signal the required 2.5V offset by configuring the op-amp as a "follower with gain." The gain is two and is set by the formula: (R4/R3) + 1. The reason for the gain of two is that R5 and R6 essentially form a divide-by-two circuit. The resistors in this circuit (R3-R6) should not be modified. Neither should the voltage divider formed by R7 and R8 that develops the 2.5V offset. The loading of R5 and R6 on the 2.5V is negligible.

The circuits of IC1.2 and both halves of IC2 perform a programmable amplification function. The three circuits are essentially identical except for the gain values. This description references the circuit of IC1.2. The values of the feedback resistors (R10 and R11) need to be determined based on your specific requirements. The gain of the circuit is RFB/R9 (RFB is the feedback resistor). You can calculate the resistor values based on the signals you want to measure and the gain required to get 1 VRMS. IC3 is an analog switch that allows you to select between two gain values for the stage by switching R11 in or shorting it. With the switch closed, the gain is 1 (0 db); with the switch open, the gain is 10 (20 db). The reason the switch for R11 (IC3) looks backwards as compared to IC4 and IC5 is that the board was easier to lay out with pins 1 and 2 reversed.

These resistor values and the relay allow for the following attenuation/gain values: attenuation = 28:1 (about -30db); gain = 0 db, 10 db, 20 db, 30 db, 40 db, and 50 db. You can also get attenuation values of -10 db and -20 db by using the attenuator and the appropriate gain values. I have elected to use 1% resistor values since



■ FIGURE 3. The input amplifier/attenuator.

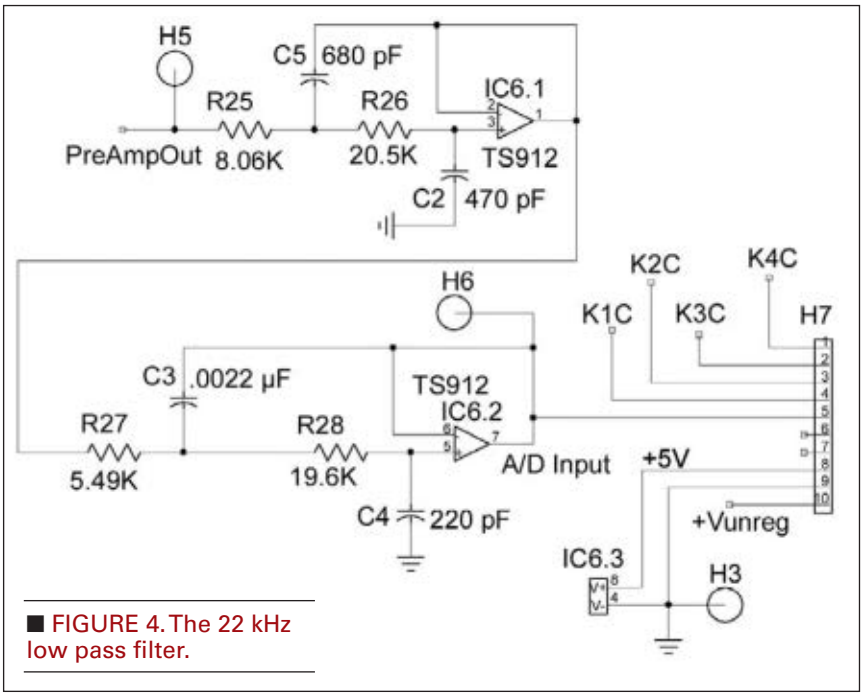
they are the same cost as 5% values (as SMD resistors). Also, an error of 1% is equivalent to only 0.09 db.

There are two procedures that must be used to calibrate the ADC and the FFT processing:

1) Measure the no-signal DC offset voltage. You can do this by simply not activating K1 and not applying an input signal. Also, each of the analog switches must be turned on so that the gain of each of the three stages is one. The voltage will be very close to 2.5V and is subtracted from all the readings in order to present the FFT algorithm with a series of values centered on 0 volts — a requirement of the algorithm. This ADC value — that should be close to 2048 — is stored into the configuration memory area.

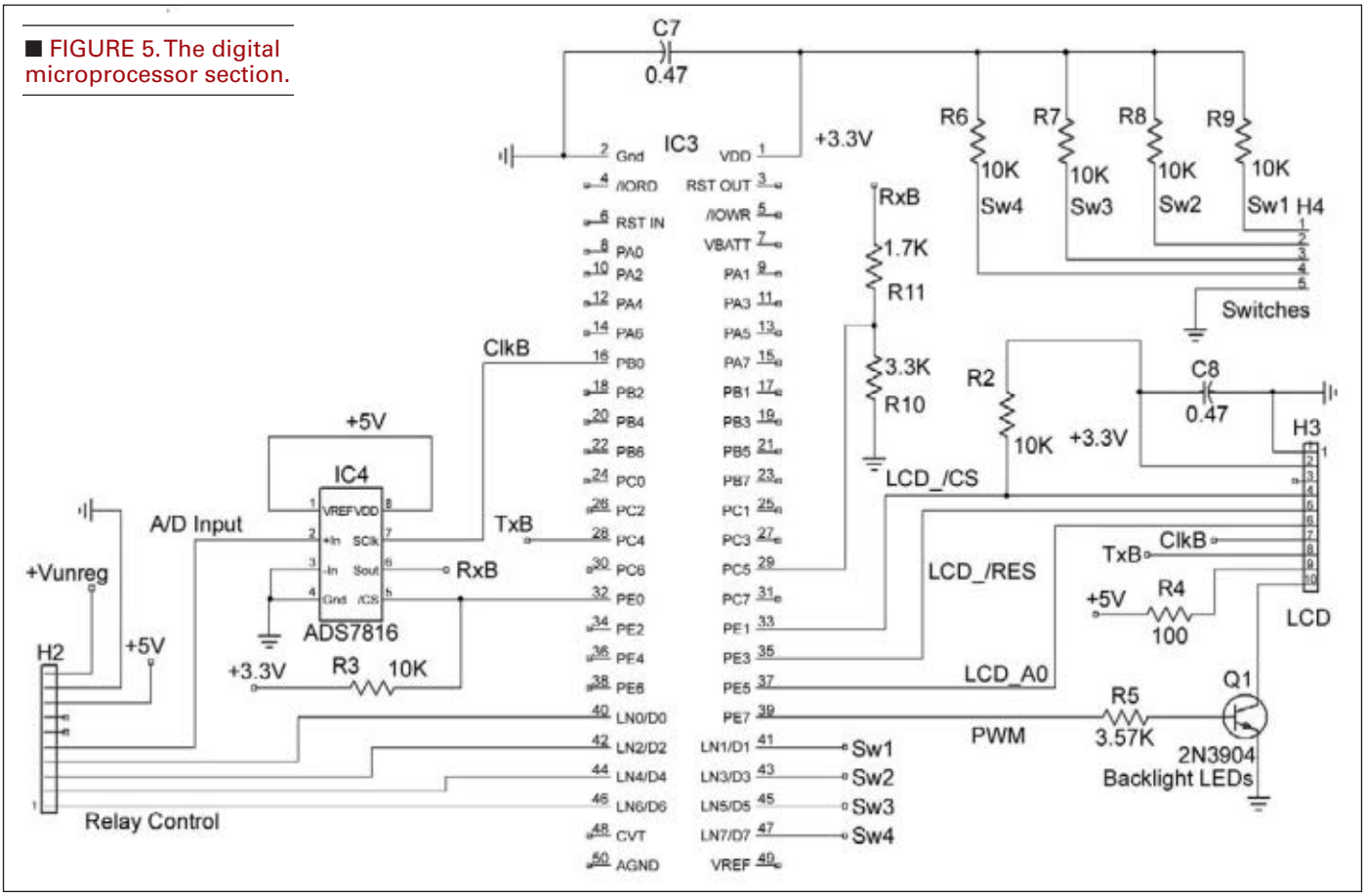
Note that there is an adjustment potentiometer for each of the gain circuits. These are required due to the offset voltages and currents of the op-amps. There is a menu option that allows you to activate and deactivate the analog switches so that you can use the potentiometers to "balance" the output voltage to the same value whether or not the switch is activated. When done, the voltage should be very close to +2.5V, independent of the selected gain.

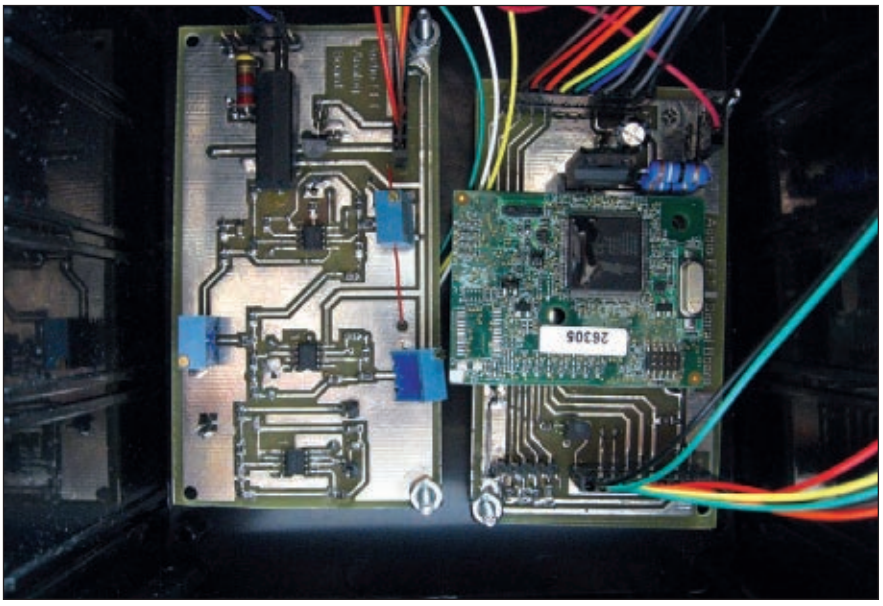
2) Measure the processed signal amplitude of a single



■ FIGURE 4. The 22 kHz low pass filter.

■ FIGURE 5. The digital microprocessor section.





■ The analog and digital boards. The digital board has the RCM4120 inserted.

frequency sine wave input. This procedure allows you to adjust the input signal amplitude and will store both the processed and unprocessed amplitudes. I suggest 0 dBm or 1 VRMS — see the discussion that follows. The calibration function displays the value of the input signal you are using for calibration so that you can monitor it while adjusting it. This yields the best calibration for the system.

Note: The "processed" amplitude is the output value of the FFT algorithm.

The maximum signal presented to the ADC must be less than 5V peak-to-peak, about 1.7 VRMS. I suggest that you use 0.7 VRMS as a standard because it is equivalent to 2.0V peak-to-peak, as well as 0 dBm into 500Ω and makes a nice reference value. You could also use 1 VRMS since this would be 2.828V peak-to-peak. Both leave a little "headroom," but not a whole lot. The resistor values I show on the schematic are based on the following two examples.

1) Suppose you want to monitor the output of a 100W power amplifier that is driving an eight ohm speaker. The output voltage at full power is therefore: V = sqrt(100*8) = 28.3 VRMS. In order to measure this signal, you need to divide it by 28. A set of "reasonable" resistors is then: R1 = 2.7K and R2 = 100 ohms. I have designed the circuit board so that R2 is an SMD and R1 is a thru-hole part so it can be 1/2 watt. By not activating K1, the attenuator will be used giving the overall circuit a "gain" of 1/28. There is a disadvantage to this circuit — it gives the audio circuit an input resistance of 2.8K. If this is not acceptable, you can increase the resistor values — but not too much or the ratio will be affected by R5 and R6.

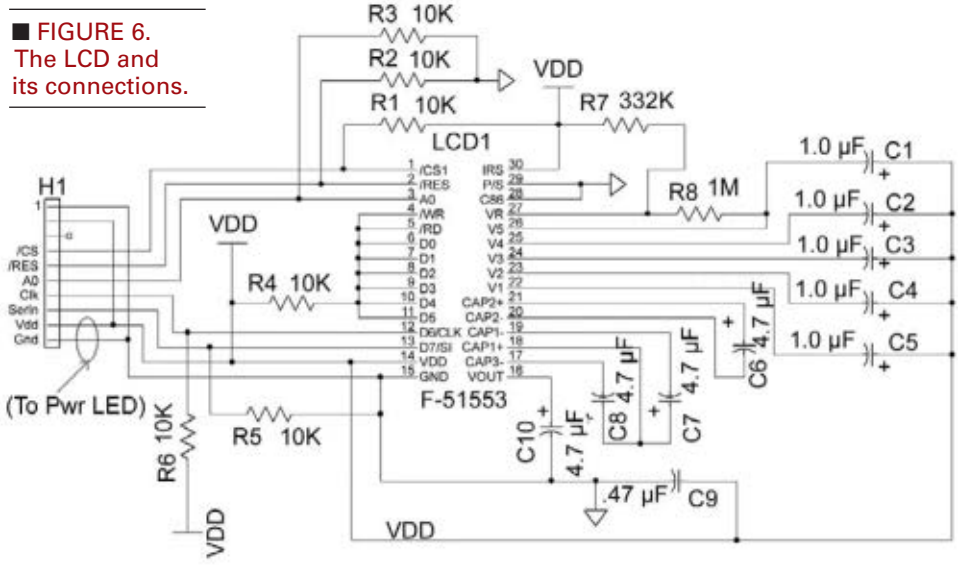
2) Now, suppose you want to monitor a signal that is 100 mVRMS. All you have to do is multiply it by 10. Using the values shown in the schematic: With IC3 turned off, the gain is (1K+9K)/1K that is a voltage gain of 10 (20 db); with IC3 turned on, R11 is shorted out that would yield a gain of 1 (0 db).

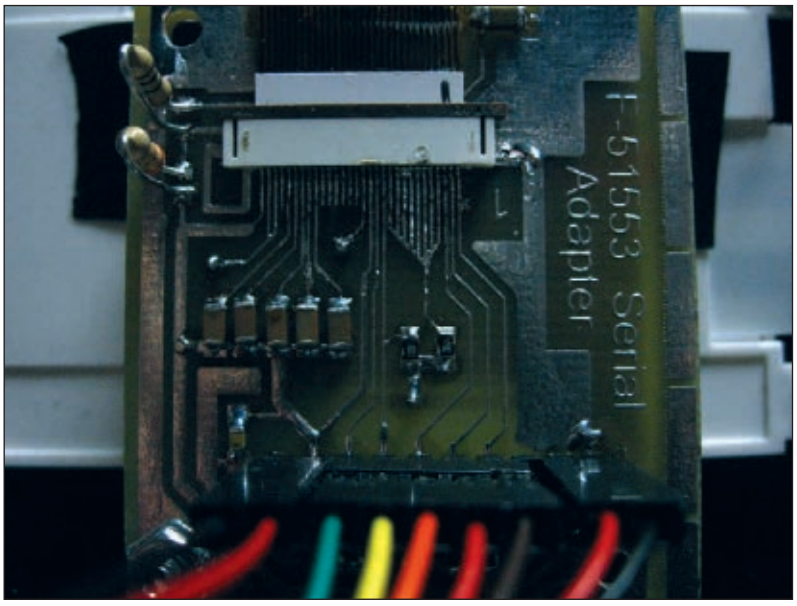
The program has a feature that causes it to read calibration values from its Flash memory when it first starts. I have set up the program so that if it detects that no calibration values have been previously stored, it will use default values that should be very close — assuming the circuit is built with the values in the schematics.

The circuit has enough gain for a typical microphone if you use the suggested transformer. Most mics have an output voltage of about -60 dbm (0.7 mV into 500Ω). The transformer has a gain of about 12 db, so with the available gain of 50 db that should be adequate for most mics. Note that there is also voltage available for mics that need phantom power. This should be applied to the primary of the transformer as shown in Figure 7.

One of the requirements of the FFT is that you must sample the input signal at least twice as

■ FIGURE 6. The LCD and its connections.



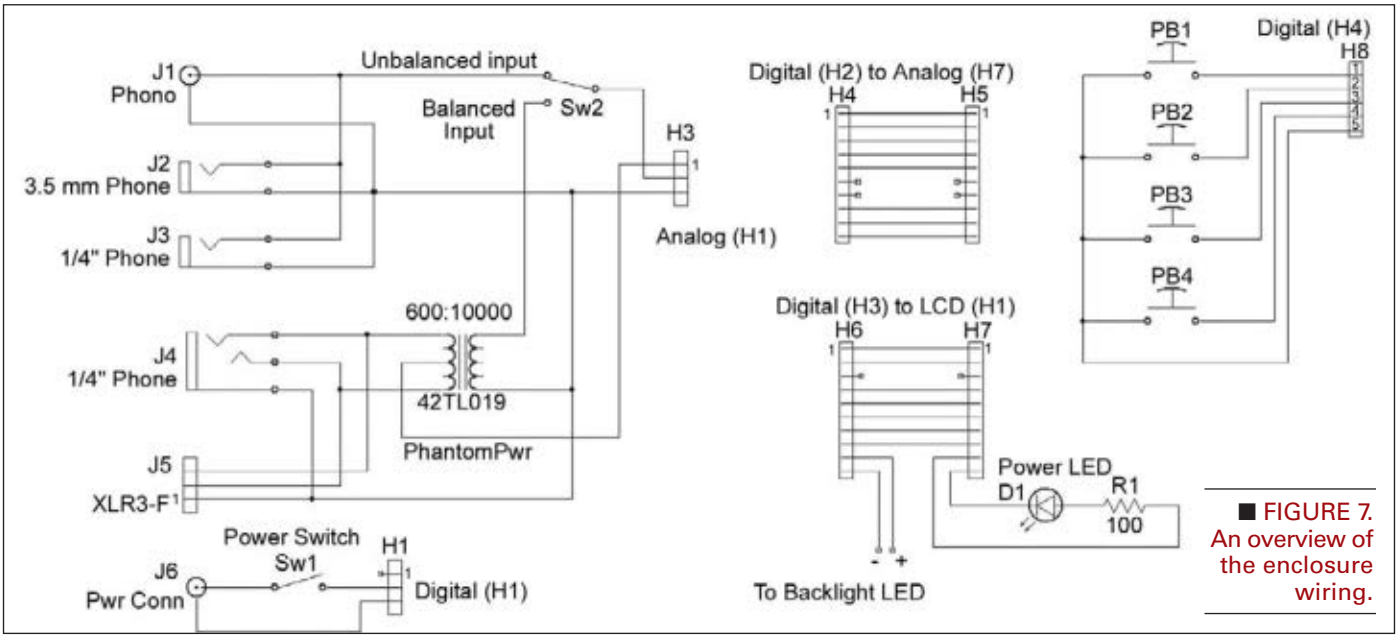


■ The LCD interface board showing the fine pitch connector and copper traces.

fast as the highest frequency being analyzed. This sampling frequency is called the Nyquist limit after an early developer of sampling theory. One of the anomalies of the FFT is that input frequencies above one half the sampling frequency will be "mirrored" into the lower frequency range of the results. For instance, if the sampling frequency is 40 kHz, the highest input frequency that should be applied is 20 kHz. However, if a signal of 21 kHz is applied, it will be displayed as if it were 19 kHz. This is one of the limitations of this system. There are two ways of getting around this: (1) insert a low pass filter with a sharp cutoff at the highest frequency of interest; or (2) sample at a higher rate than necessary. The disadvantage of the low pass filter is that it should be programmable. The disadvantage of the high sampling rate is lower resolution. The resolution of the system can be calculated as follows: Resolution = Sample Frequency/(2*Sample Size). The factor of 2 is due to the FFT algorithm that I am using.

I have decided to include an active low pass filter (Figure 4) with a cutoff frequency of 22 kHz. The filter is a four pole Sallen-Key design and can easily be bypassed if you do not want to include it. The design I used was found at **http://beis.de/Elektronik/Filter/ActiveLPFilter.html**. This site allows you to modify the characteristics of the filter on-line and calculates new values for you. I have no idea how sensitive the filter characteristics are relative to the component values. However, I did measure the response of the filter in the circuit and it is quite good: at 20 kHz it has about 1.2 db loss; at 24 kHz it is about 4 db. I suggest that you use a sampling frequency of about 45 kHz if you are going to analyze signals with frequency components up to 20 kHz. This should allow the filter to remove most — if not all — of the higher frequency artifacts. Another limitation of the system is the display frequency resolution; 100 columns are used for the FFT display. Based on the formula above for resolution, at a sample frequency of 45 kHz and a sample size of 512, the resolution is 43.9 Hz. Since the data is displayed in 100 columns, that essentially means that the total span of frequencies displayed must be a multiple of 100 *43.9 or 4390 Hz. In practical terms, this says that if you tell the system that you want an upper frequency of 10 kHz displayed, you will actually get 4390*3 or 13.2 kHz.

My original design had the analog circuits on the same board as the processor. I decided to move them to a separate board for two reasons: (1) to keep digital noise



■ FIGURE 7. An overview of the enclosure wiring.

PARTS LIST

ITEM	PART NUMBER	QTY
❑ Housing	103158** (Jameco)	2
❑ Socket pins	100766** (Jameco)	55
❑ Header	160882 * (Jameco)	2
❑ PB switch	104-0013-EVX	4
❑ SPST switch	108-1MS1T1B1M1QE-EVX	1
❑ SPDT switch	108-1MS1T1B1M1QE-EVX	1
❑ Power connector	163-2325-E	1
❑ Power connector	1710-2532	1
❑ 3.5 mm Phone jack	161-7300-EX	1
❑ XLR3-F	164-7133	1
❑ 1/4" Phone jack	16PJ022	1
❑ Phono jack	16PJ052	1
❑ 1/4" Phone jack	16PJ080	1
❑ 10Ω 2W	282-10-RC	1
❑ 1K	292-1.0K-RC	10
❑ 1M	292-1.0M-RC	1
❑ 1.7K	292-1.7K-RC	1
❑ 100K	292-100K-RC	1
❑ 100	292-100-RC	2
❑ 10K	292-10K-RC	12
❑ 19.6K	292-19.6K-RC	1
❑ 2.1K	292-2.10K-RC	1
❑ 20.5K	292-20.5K-RC	1
❑ 3.3K	292-3.3K-RC	1
❑ 3.57K	292-3.57K-RC	2
❑ 332K	292-332K-RC	1
❑ 47K	292-47K-RC	1
❑ 5.49K	292-5.49K-RC	1
❑ 8.06K	292-8.06K-RC	1
❑ 9K	292-9.09K-RC	1
❑ 100Ω	30BJ250-100	1
❑ 2.7K	30BJ500-2.7K	1
❑ 42TL019	42TL019	1
❑ TS912	511-TS912BID	3
❑ FAN1616	512-FAN1616AD33X	1
❑ GF1A	512-GF1A	2
❑ 7805	512-KA7805ATU	1
❑ Socket	538-52437-3072	1
❑ Socket	571-5-104652-5	1
❑ 220 pf	581-08051A221K	1
❑ .0022 µF	581-08053A222K	1
❑ 470 pf	581-08055A471K	1
❑ 680 pf	581-08055A681K	1
❑ .47 µF	581-0805ZC474K	8
❑ Enclosure	377-1163-ND (Digi-Key)	1
❑ 2N3904	625-2N3904	2
❑ 100 µF	647-UVR1E101MED	1
❑ 20K	72-T93YA-20K	3
❑ F-51553	805-F51553GNBJAEN	1
❑ Relay	806-9081C1-05-00	1
❑ 1.0 µF	80-C1206C105K3R	5
❑ 4.7 µF	80-C1206C475Z4V	4
❑ ADS7816	ADS7816U-ND (Digi-Key)	1
❑ Microprocessor	RCM4120	1
❑ SN74LVC1G66DBVR	296-13253-1-ND (Digi-Key)	3
❑ LED	606-CMD3750	1

* 160882 Headers are cut to size and require 100766 pins and housing
** 100766 socket pins requires 103158 housing cut to size
The system needs about 55 total pins — this is equivalent to two pieces each of 103158 and 160882
NOTE: All items are from Mouser unless stated otherwise.
A more detailed parts list is available at ***www.nutsvolts.com****.*

away from the analog amplification stages as much as possible; and (2) to enable the flexibility in the audio processing so the builder can develop his/her own circuit and control it from the system.

The processor circuit (Figure 5) shows the connections from the microprocessor board to the other circuits. The board also has the A-to-D converter and the pull-up resistors for the switches. The ADC is powered by the 5V regulator. As such, its SPI output signal is a 5V logic level. The microprocessor board I am using can handle only 3.3V input signals — that is why there is a voltage divider on the output of the ADC.

I have selected a 2 MHz clock speed for the SPI system. This is used for both the analog converter and the display. The interrupt service routine that is used to sample the input signal takes approximately 12 to 16 µs, depending on the processor you are using. This means that the highest theoretical sampling frequency is either 80 kHz or 60 kHz. The fastest sample rate the ADC will support is 200 kHz. This is equivalent to an SPI clock rate of 3.2 MHz since it takes 16 SPI clocks to read the converter. The display can handle about a 7 MHz clock. So, I could increase the clock speed to 3 MHz and get a 50% increase in the sample rate. However, this is not necessary since the system is designed for the audio spectrum.

All of the values can be modified via the menu system can be stored in the Flash memory of the microprocessor board. This includes the ADC calibration, the frequency "window" you want to view, sample size, etc. The current menu system allows you to store up to 10 sets of these values. There is a complete and detailed description of the menu system on my website at **www.qsl.net/k3pto**.

Some Construction Notes

A few comments about the BOM. Although the BOM shows mostly Mouser part numbers, many of them are available from other sources, including Digi-Key and Jameco. If you want to save some money, I suggest you search the sites for the best prices on the higher cost items. Bear in mind that these companies may have a minimum dollar value for orders. Many of the parts for this project do not have critical values. For instance, the gain resistors in the analog circuit may be customized for your application. The transistor type used for K1 on the analog board and the backlight on the digital board can be any small signal NPN or even an FET (2N7000). The PCBs (three) can be purchased from FAR Circuits as a set.

I recommend that you purchase two of the LCD boards, as well as two of the LCD connectors.

Soldering the LCD connector to the board is the most difficult part of this project. I highly recommend using a 3X, lighted magnifying lens (5X would be better). I also used a 10X eye loupe to make sure of the connections and that there were no shorts. Soldering with a very fine tip is required — I use a .030" tip. One suggestion for soldering is to tin the leads of the connector using fine solder, align the connector, solder the tab near pin 1 to keep it in place, then heat the pins with a clean soldering iron tip. This method takes advantage of the tinned circuit board and prevents the application of too much solder that could create shorts between pins. I highly recommend that you use .015" solder; using thicker solder will probably cause you to create shorts between adjacent pins. You should also have some solder wick on hand.

I like to use single row pin headers for my I/O connections. Their cost is about $.15 per point if you buy enough to do 100 points. I like this method because it allows me to disconnect all the sub-systems. If you do not want to use these connectors, you can easily just solder wires into the header location points. If you do use the connectors, I suggest that if you are hand crimping, you keep the socket pins on the strip while crimping with a small pair of needle-nose pliers. A better solution is to have a crimp tool available — but these are somewhat expensive. Whatever method you use, you should strip 1/8" of insulation off each end to make a good connection.

You need mount only the input sockets you need for your application instead of all the ones I have shown in the enclosure schematic (Figure 7). The schematic does not show any connections to the high level input (H2). You can mount and connect any appropriate sockets your application requires. Another possibility is to use a switch to connect J3 to either H1 or H2 of the analog board.

You may use whatever switches you like for the power and pushbutton switches. I selected ones from the Mouser catalog based primarily on cost.

My website has a number of JPEG files to aid you in assembling the circuit boards. There are three files for the analog and digital boards and two for the LCD board. These files include: top side silk screen, bottom side silk screen, and vias. The silk screen files show parts placement and the via files show the locations of the vias. The via locations are needed because my vendor for the boards does not do plated-thru holes. You will have to insert wire jumpers in all the via locations. This also means that a number of components need to be soldered on both sides of the boards in order to complete the circuits.

The wiring between the subsystems should be done with fairly flexible wire. I happen to have a supply of eight conductor telephone cable. This is an advantage because it is multi-color that makes tracing signals easier. I was able to use this effectively by first cutting the cable to the required length, then removing the wires from the outer sheath. Let me know how your build goes. **NV**

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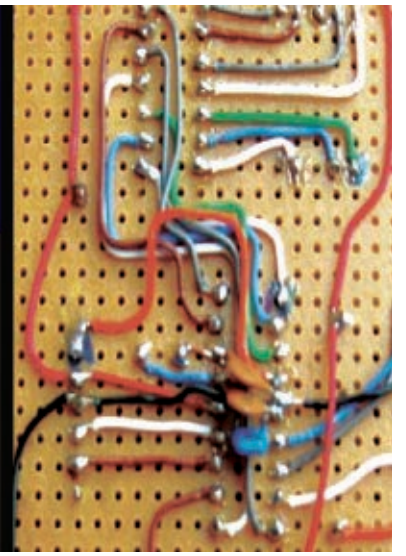
How To Use the Pushbutton Rotary Encoder

by Jack Botner



Learning how using a pushbutton rotary encoder can help you design and build better, more user-friendly microcontroller projects.

I was bitten by the microcontroller bug a number of years ago and enjoyed building a variety of gadgets that use them. One of the tedious aspects of gadget building is the buttons and switches that make up the input controls. When I discovered the pushbutton rotary encoder, I realized that one control could replace many, simplifying the design, construction, and programming.

This article will introduce you to the Greyhill 62P22-L4 pushbutton rotary encoder[1]. I will describe what it is, how it works, and how to integrate it into your project. A demonstration will be presented using a PIC16F84A[2], along with the project code written in C.

The Greyhill 62P22-L4

I chose this device more or less at random, because it was in stock from my favorite supplier. The shaft rotates with soft detents, and can be pressed in as a pushbutton. Each detent is at 22° of rotation. There are no stops and no reason why it cannot be rotated endlessly either clockwise or counter-clockwise. This model comes in two different rotational torque and two different pushbutton forces; the L4 model is the lower torque and lower force model. (Other types with a variety of features such as integrated joystick are also available.)

This rotary encoder requires a +5 VDC supply at 30 mA. It uses an internal LED and optical detector to produce its output. The pushbutton is a mechanical contact type and requires a few milliseconds to debounce (four at make and 10 at break[3]).

■ FIGURE 1. The encoder.

■ FIGURE 2. Encoder logic states.

CLOCKWISE ROTATION		
POSITION	OUTPUT A	OUTPUT B
1		
2	•	
3	•	•
4		•

•INDICATES LOGIC HIGH; BLANK INDICATES LOGIC LOW. CODE REPEATED EVERY FOUR POSITIONS

The rotary encoder outputs a two bit binary code on its Output A and Output B pins. This gives four unique values, after which the code repeats itself. Once you know the previous and current output values and the code sequence, you can determine which way the shaft has been rotated.

If you assume that Output A is the low order bit and Output B is the high order bit, when rotated clockwise the encoder outputs 0, 1, 3, 2. When rotated counter-clockwise, the output is 0, 2, 3, 1. (There is,

of course, no reason why the bit order could not be reversed and the output sequence changed correspondingly.)

To produce a number in the sequence shown, place Outputs A and B in a byte in working storage like this:

bit 7							bit 0
0	0	0	0	0	0	B	A

At startup, the program must read the encoder value, since it could output any of its four values. The value is saved in memory as the previous value. The encoder is then polled until the value changes. Comparing the previous value and current value to the sequence 0, 1, 3, 2, you can tell which way the shaft has been rotated and act accordingly. Then the current value is saved as the previous value and polling continues.

Note that the encoder outputs require pullup resistors. In my demonstration example, I use the internal pullups available at port B of the PIC16F84A for the encoder and the pushbutton. Otherwise, 10K resistors to the +5V supply are recommended.

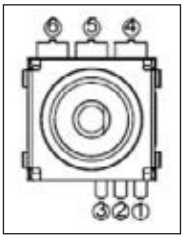
The pushbutton is debounced and read like any pushbutton. According to the specifications, the longest settle time is 10 milliseconds — which is pretty fast — so your code can be responsive to button presses.

Finally, the encoder supply pin requires a 150 ohm resistor between it and the +5V supply. The encoder's pinouts are shown in Table 1.

Pin	Description
1	Supply (+5 VDC through a 150 ohm resistor)
2	Ground
3	Output B
4	Output A
5	Pushbutton
6	Pushbutton

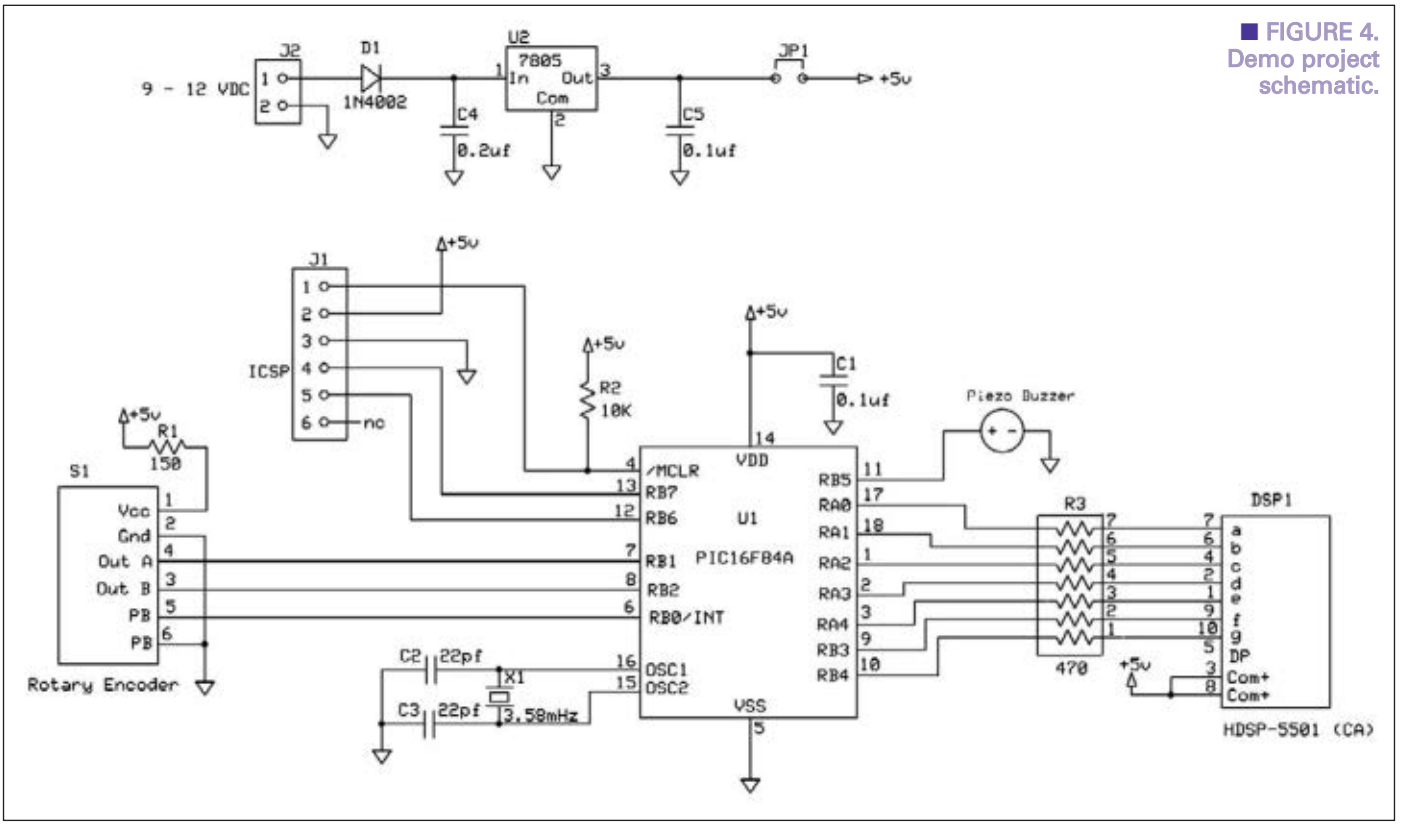
■ TABLE 1

What Can I Do With It?



■ FIGURE 3. Pin numbers viewed from the top.

The obvious use of the encoder is for the clockwise rotation to signal an "up" type event, the counter-clockwise rotation "down," and the pushbutton to signal some kind of request or mode selection. For example, let's say you are designing a programmable thermostat with an LCD readout. You want it to control either a furnace or air conditioner, so it has three states: cool, heat, and off. You could use up and down buttons for the temperature, and a three position switch for the state. Or, you could use an encoder. Rotating the shaft raises or lowers the temperature setting. Pressing the button changes the mode, activating a menu which allows you to select heat, cool, or off (by rotating the shaft). Pressing the button



■ FIGURE 4. Demo project schematic.

again returns the unit to run mode.

This is a very simple thermostat, but it is now easy to extend the design with more features, taking advantage of the flexibility of the encoder and LCD display. You can add a clock and time of day programs; you can set the clock; you can add a fan on/off function; and so on, without having to add any more hardware to your design.

Another application is a power controller, possibly to control the temperature of a soldering iron. The pulse width modulation feature of many microcontrollers is ideal for power control of a resistive load, with the help of a power MOSFET. The device could have a one or two digit LED display showing the power level, and a rotary encoder to turn the heat up or down. The encoder's pushbutton could be used as an on/off switch. (In fact, the power would always be on to the microcontroller, but turning the unit off instructs the processor to set the output power level to zero and disable the LED display.)

If you add hardware debouncing to the pushbutton and connect it to an external interrupt pin, a press of the button can be used to put the microcontroller into sleep mode and the interrupt caused by another press used to wake it up. Battery operated applications would benefit from the decreased power consumption when the unit was off.

The Demonstration Project

This simple project uses a PIC16F84A to manage a rotary encoder as input and a single digit LED display and buzzer as output. On power up, '0' is displayed. Rotate the encoder clockwise, and the number is incremented to 9, then back to zero again. Rotate counter-clockwise and the display becomes '9' and decrements down to 0. Pressing the encoder pushbutton makes the buzzer sound.

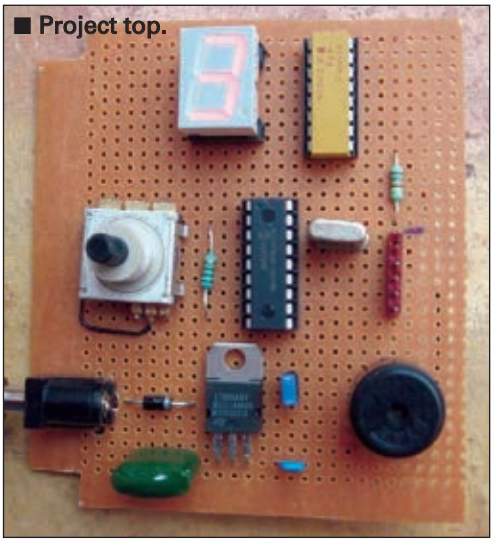
The rotary encoder S1 is interfaced to U1 with three I/O pins configured as inputs. The port B internal pullups are used for each PORTB input port, so external pullup resistors are not needed. The PIC uses a 3.58 MHz crystal oscillator, but any crystal up to the maximum frequency supported by the PIC is okay, as long as the timer0 interval parameters are adjusted accordingly. J1 is used for in-circuit Flash programming (I use a Pickit2[4]) and is not required for operation. The buzzer and the LED display are connected to the remaining I/O pins configured as outputs. (If you don't want to bother with a buzzer, just replace it with an LED and 470 ohm limiting resistor.) U2 provides regulated five volts so that a battery or wall wart can be used to power the project.

The Software

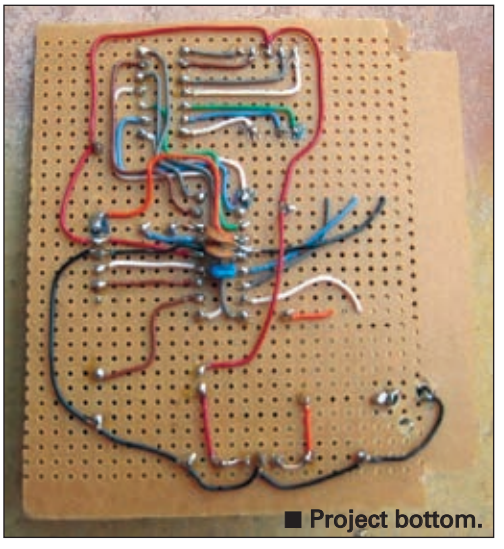
The hardware design of microcontroller projects is deceptively simple, because so much of the work is done in the software. Polling for input events is a major task, which must be carefully coordinated with the other work being done by the processor. Improper or poor design may result in input events being missed or responded to sluggishly. The way I manage this problem is to use the PIC's timer to do all the input polling and switch debouncing. It then posts event flags to the foreground code, which is free to respond to events as they occur.

This architecture works well when an event signals an action that can be processed quickly. I do this for my encoder inputs, where I am incrementing or decrementing the display. Other kinds of events that require time to perform can be more difficult to handle. For my button press, I want to sound the buzzer for a period of time, but I do not want to tie up the main code with a long delay. In this case, the solution is to sound the buzzer in response to the button press, and then schedule an event to turn the buzzer off later (conveniently done in our timer interrupt routine). The benefit is no time-wasting delay loops at all in the program.

To see how the rotary encoder is managed in the software, have a look at encoder_demo.c and encoder_demo.h in the downloads available on the Nuts & Volts website at **www.nutsvolts.com.**



■ Project top.



■ Project bottom.

1) In function **InitCPU**, the option register is loaded to assign the prescaler to timer0 and set the prescaler to 16:1. The timer0 counter TMR0 is initialized to the value in define TIMER0_INIT. Note also that PORTB pull-ups are enabled. Then timer0 and global interrupts are enabled.

2) An interrupt handling function **isr** (PICC) or **interrupt** (BoostC) is provided to handle timer0 interrupts. The choice of

prescaler and timer0 counter initialization value, along with the crystal frequency, determine the interrupt interval, chosen to be four milliseconds (but not particularly critical for this application). Comments in the code further explain how these values have been derived.

The main activity is to call **debounce_switch**, the function that polls each input pin and performs the input debouncing. There are no parameters, since global variables in memory are used to manage the debouncing states. If any input level changes, an event flag is set for the main code to deal with.

The secondary activity is to look for the beeper being on, and count down to zero and turn the beeper off.

3) Function **debounce_switch** polls each input (two encoder and one pushbutton) and keeps track of the state, returning the current state in global variable **ucDebouncedState**.

4) Function **analyze_switch** is called by the main code in response to an input changed event. This function determines if the button was pressed or the encoder shaft turned clockwise or counter-clockwise. A corresponding event bit is turned on for the mainline to process.

For the encoder, the method used is to isolate Output A and Output B as the lowest two bits in a byte as described above and see how it compares to the previous value.

Button presses are detected but not button releases. An event for button release could be added if necessary, or a global variable set to 1 when the button was down.

5) The **main** function looks for the various event flags and performs the required processing.

References

[1] http://lgrws01.grayhill.com/web/images/ProductImages/Series62PEncoder.pdf

[2] http://ww1.microchip.com/downloads/en/DeviceDoc/35007b.pdf

[3] www.ganssle.com/debouncing.pdf

[4] www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1406&dDocName=en023805&redirects=pickit2

Conclusion

I hope you found the rotary encoder as interesting as I have. It is easier to design a project to use one in place of a number of other input devices. It is also easier to build a project with one input device instead of many, and the project may be simpler for the user to operate, as well. **NV**

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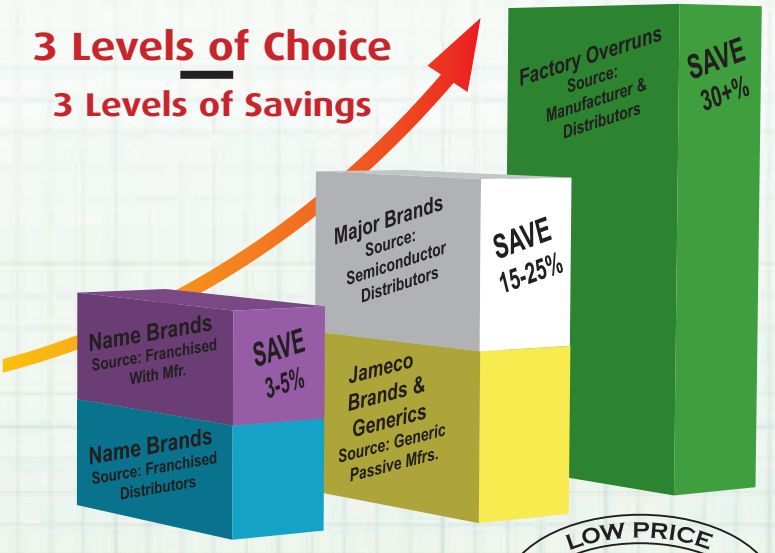

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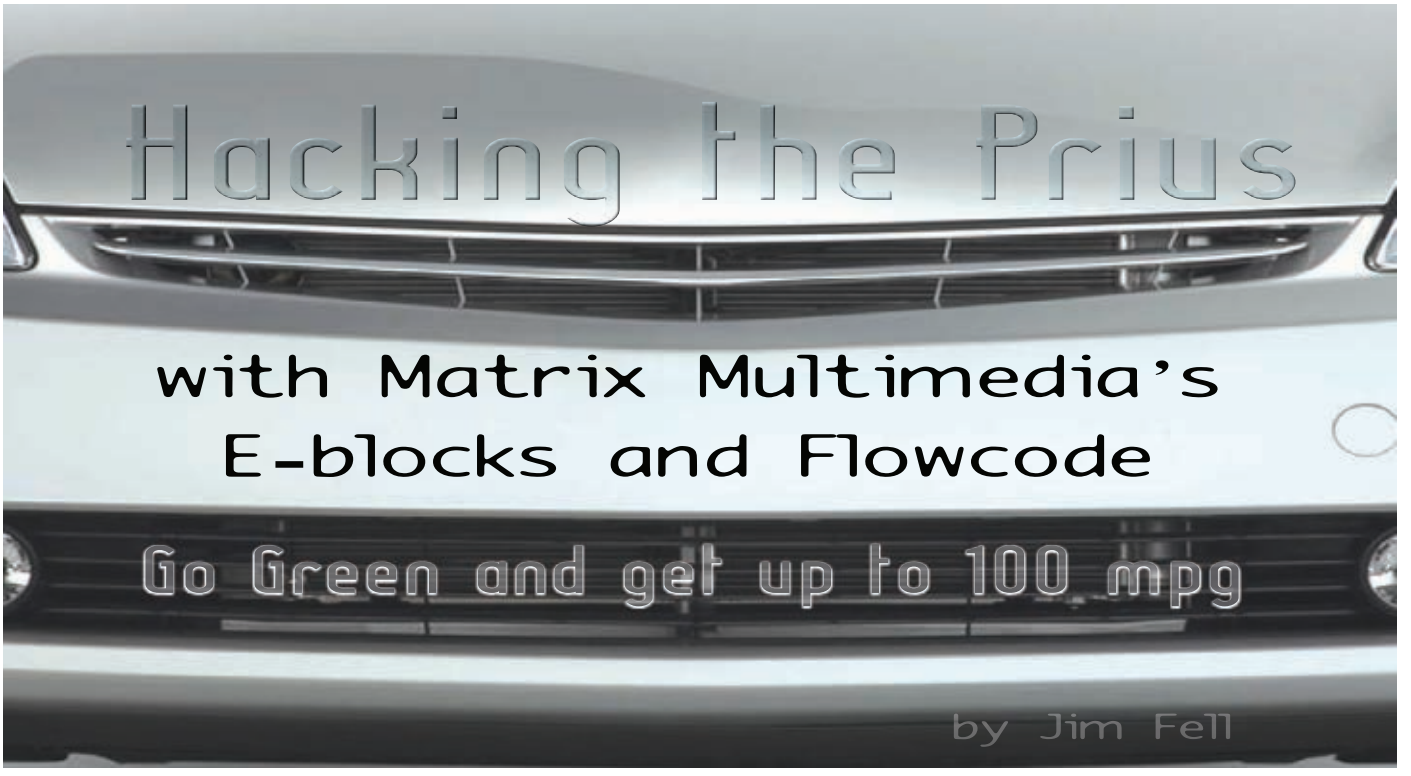


Hacking the Prius

with Matrix Multimedia's E-blocks and Flowcode

Go Green and get up to 100 mpg

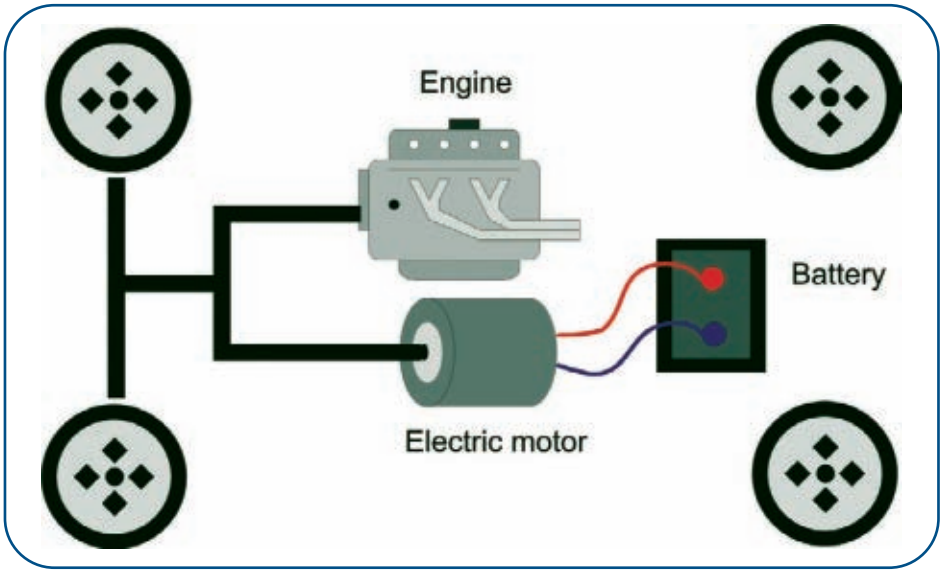
by Jim Fell

I first converted a car to purely electric operation in 1999 and after several improvements — particularly to the battery pack — the car was moderately successful. I was generally able to travel about 50 miles on a charge and considerably more if care was taken. The car completed the London to Brighton Electric Vehicle (EV) Run in 2005 and 2006.

Unfortunately, the achilles heel of the EV is still the battery pack. With low cost, traditionally lead-acid batteries the range is severely limited and a long, cross-country run must be planned like a military campaign. There must be charging points every 50 miles or so, and you need to stop for a couple of hours at each to restore some charge.

In 2005, I started looking at the hybrid cars that were available and the Toyota Prius in particular. The interesting thing about the Prius was that it could run for a limited period as an EV, however with the NiMH battery pack the electric motor can take the car only about one mile at less than 31 mph. I wanted to reduce the fuel consumption of the Prius from 60 mpg to 100 mpg — a massive cost savings — by the addition of a large Li-Ion pack. This article described how I achieved this using E-blocks and Flowcode from Matrix Multimedia as a control system.

■ FIGURE 1. The basic topology of the Prius drive system.



How It Works

Figure 1 shows how the Toyota Prius works. Essentially, it is a normal car with the addition of an electric motor/generator in the drive train. When the driver needs to slow down, the brake pedal puts the 'motor' into generator mode which charges the battery up. Conversely, at low speeds the motor is used to assist the conventional petrol engine which decreases fuel consumption.

When I started the project, a few groups in the US were experimenting with supplementary battery packs to increase the range of the Prius. The Toyota — along with most modern cars — has a very complex electronic control system. The part that deals with drive and battery management uses CANbus for communication. The operation of the drive among

other things is based on the State Of Charge (SOC) of the battery pack. If the SOC is low, the management system will recharge when descending a hill, braking, or use any surplus energy from the engine. If the SOC is high, then the battery pack will be used to drive the car at low speed or to supplement the engine when driving, climbing hills, or overtaking. In practice, the SOC is moving about the entire time, dependent upon traffic and driving patterns.

I saw two main problems in adding a large battery pack in parallel with the existing battery. The first was what would the reaction be from the Toyota management system if — out of the blue — the existing battery started receiving charge from an outside source — the second battery! The second problem was how to control this external charging source.

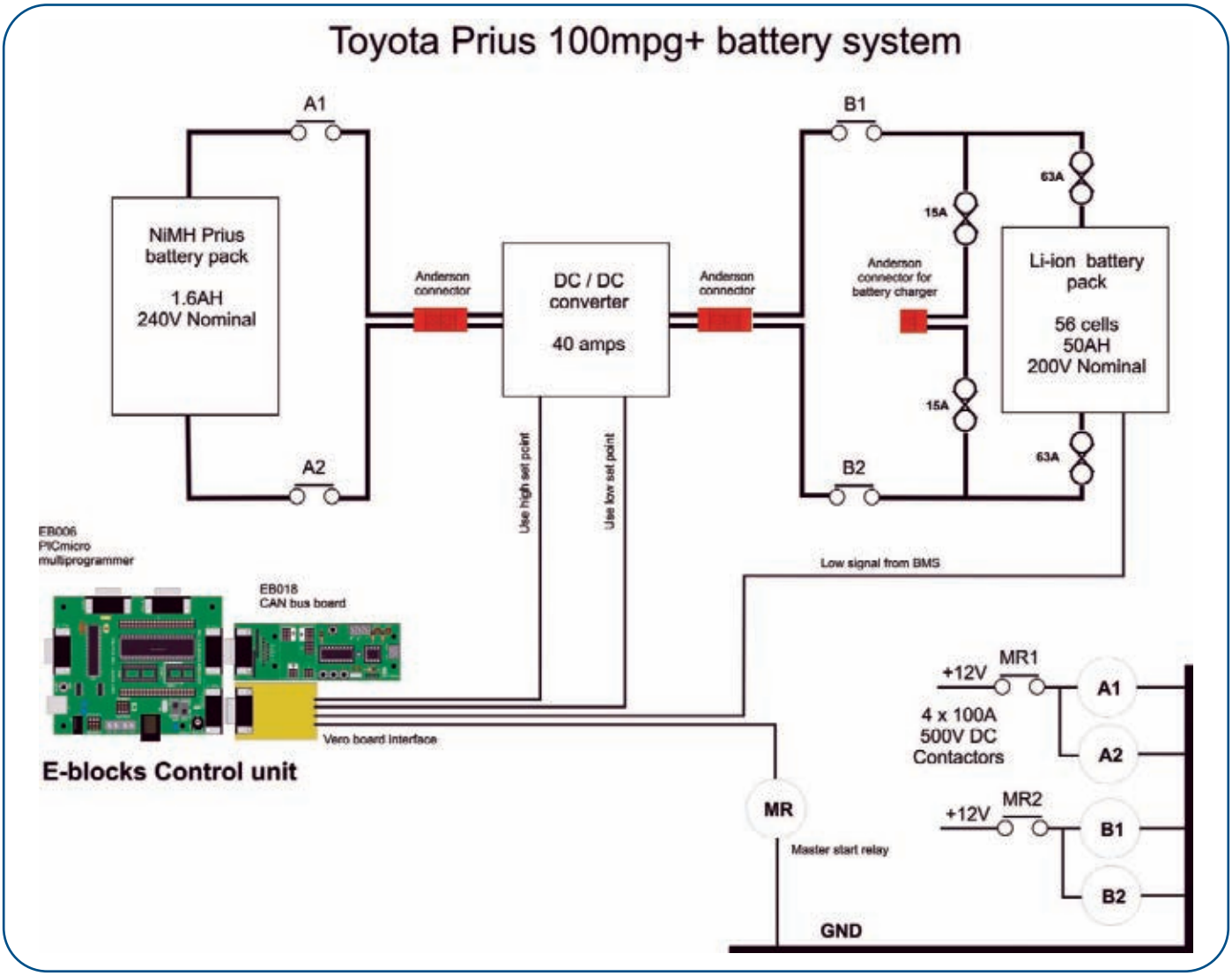
The control system needed to be such that the existing batteries' SOC could be manipulated so that the Toyota management system saw a high SOC and used the battery instead of the engine wherever possible.

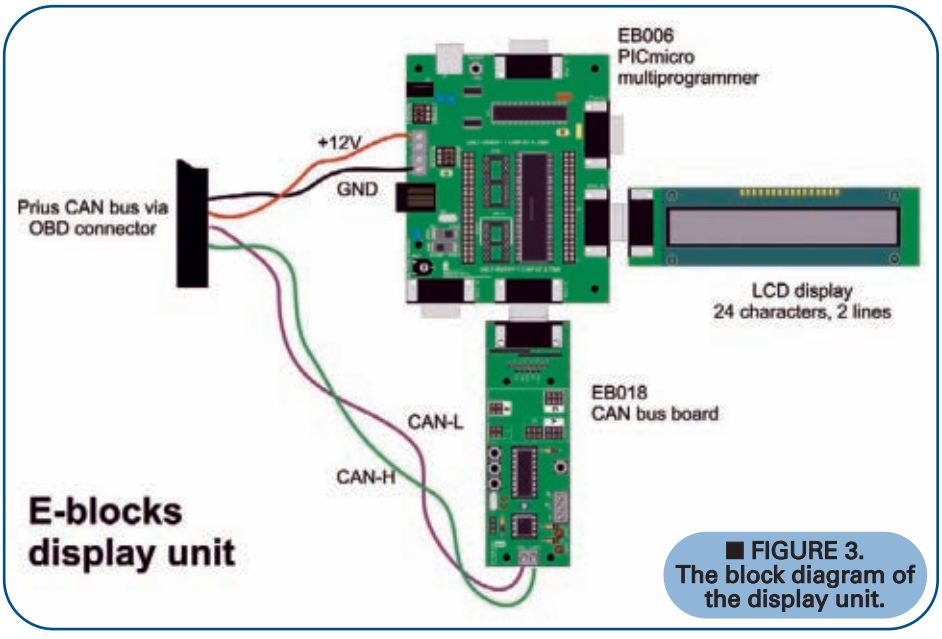
The first problem was simple. I connected my EV charger across the Toyota battery pack and charged the pack. The SOC increased up to fully charged (about 80% SOC). The battery manager took into account the pack temperature and voltage, and computed the SOC quite happily. Solving the second problem — transferring energy to the Toyota's battery — was the main area of work.

Circuit Details

I was lucky enough to have acquired a set of 56 Thunder Sky Li-Ion cells which I could use as a second battery. These are connected in series to give a resulting DC voltage of around 210V and more than 50 Ah. The Toyota's NiMh battery produces around 240V DC, so I knew that I would need an inverter to allow the additional battery pack to charge the Toyota's own battery. I also wanted to be able to recharge the Li-Ion batteries overnight, so I needed a recharge circuit. I needed a circuit to control the flow of charge into the Prius' own battery, as well. You can see the circuit in Figure 2.

■ FIGURE 2. Block schematic of the system.





■ FIGURE 3. The block diagram of the display unit.

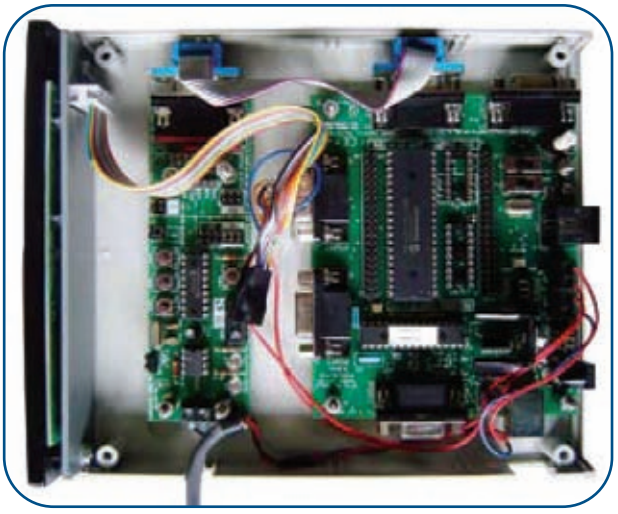
The means of connecting the extra battery pack to the existing pack was by using four single pole, high voltage power contactors and a high power DC-DC converter.

The converter is actually a battery charger which has a bridge rectifier as the first component to convert the normal AC mains input to DC. Of course, you can just feed it with DC. The DC-DC onboard converter is used to charge the Li-Ions if required, but that's another story.

The converter had a two-stage, selectable output. In high, the converter would try to lift the existing pack to a high voltage and thus a high SOC. In low, this voltage was lower and allowed the existing pack to lose charge letting the SOC% to fall back. The output of the DC-DC converter is controlled by switching in one of two sets of points. When the battery is being charged overnight, it is isolated from the Toyota circuit by a second set of points.

The NiMh to Li-Ion battery contactors would be energized the whole time during vehicle operation, until the extra battery pack was fully discharged and no longer able to contribute — at which time the batteries were disconnected.

Controlling this system meant hacking into the Toyota CANbus system. The car has many devices on the CANbus network and fortunately they all broadcast their data onto the bus. The devices that need the data read it and react accordingly. As far as I am aware, no device solicits information from another device (*CANbus is arranged as one master and N slaves -Ed*). What was needed was a custom CANbus device that could read parameters on the system and move charge into the existing battery pack at the right time.



■ FIGURE 4. The display unit with multiprogrammer, CAN board, and LCD on the front.

At this point, I read an article in *Elektor* on Flowcode (February '06); this referred to a CANbus system consisting of two nodes of a network. From past experience with other bus systems, it can take a long time to get a system up and running. I have a bit of experience with Microchip PIC devices and there is a wealth of information on their website on CAN networking. The datasheet on the CAN interface chip (MCP2515) runs to 81 pages.

I ordered the Flowcode CAN system and saw immediately all the hard work of using the CANbus had been done already. Setting up the parameters for the bus and reading specific messages is carried out by prewritten macro commands. Getting the communication between two points was very straightforward.

In order to read the messages emitted containing data on the SOC, a Kvaser Light CAN to USB unit was used to look at the bus traffic. There is a convenient OBD-II connector with 12V power located just under the steering wheel in the Prius. There is some documentation regarding the messages on the bus on the Internet. The format of the data varies and a bit of manipulation is needed to convert the data to a form which can be displayed on an LCD.

With some idea of what I wanted initially from the bus, I set up a system in the workshop mimicking the function of the CAN bus in the Prius. One of the E-block systems continuously transmitted an SOC message in the same format as the Toyota message; the other system was set up as a display unit which showed the system parameters on an LCD display. This was used in the development and commissioning phases of the project on the bench, and fitted into the radio compartment of the car as shown in Figure 5. The display shows the Battery Current, Battery Voltage (charging/discharging), State of

■ FIGURE 5. The display unit in the Prius dashboard.

Charge %, Charge Current Limit, Discharge Current Limit, Max Battery Temperature, and Min Battery Temperature. In this way, the whole system could be built up and tested away from the car.

The second stage of the program used only one of the items (SOC%) and gave out one of two outputs — high or low — depending on the value of SOC. In order to maintain the existing battery SOC at around 70%, a simple pair of decision instructions in Flowcode are put on the low output if SOC% >70 (and disconnected the Li-Ion cells from the charge circuit) and put on the high output if SOC%<65 (which switched the Li-Ion cells into the circuit and charged the NiMh Prius battery). In each case, the opposite output would be turned off.

One additional output was used to drive a relay which, in turn, energized the four main contactors. This output would come on five seconds after the system powered up and would go off in response to the additional battery pack becoming discharged.

There was no need for a display on the final controller and this now lives in an enclosure in the boot (*or trunk for us Yanks -Ed*) next to the extra batteries and power contactors.

The additional battery pack is a set of 56 Thunder Sky Li-Ion cells. These cells are about two years old and vary in capacity; the worst being about 50 Ah at 20 degrees C when discharged at 25 amps. The worst cell defines the pack capacity, so with the current limit set to 25 amps the car will run for two to three hours in assist mode until the battery pack switches off. The car then runs in normal hybrid mode as before.

One drawback of the system is these batteries are still very expensive and physically quite large. Another is that the batteries take up some of the boot space as you can see in Figure 6.

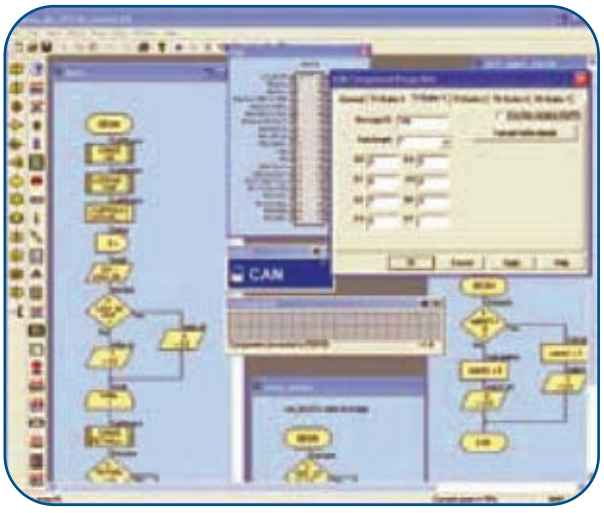
Figure 8 shows the Flowcode program. Flowcode allows users to develop a program by dragging standard flow chart icons onto the workspace and then clicking on them to enter the properties. Users can simulate this on screen, and when the program is debugged can compile the flow chart to machine code which can be downloaded to a PIC microcontroller. Flowcode includes built-in routines and dialogs for CANbus communication which allows you to easily transmit and receive packets of CAN data.

Conclusion

In summer, the car will return

■ FIGURE 6. Photos showing before and after pictures of the battery system.

■ FIGURE 7. The inverter in the boot.



■ FIGURE 8. The Flowcode software used for developing the control system.

about 60 mpg in normal hybrid mode and about 100 mpg in battery boost mode. Unfortunately, the Prius' read-out only goes to 99.9 mpg so you are a bit blind as to how well it's really doing. In Figure 9 you can see a photograph of the Toyota's display which shows that the car has achieved at least 99.9 mpg.

Another job for Flowcode will be to read the instantaneous fuel flow from the bus along with the speed and compute the real fuel consumption.

Further gains can also be made by reading the bus speed signal and pulsing a relay when the speed drops below 30 mph to force the car into EV mode. The relay would be pulsed again on the speed rising to 30 mph to take the car out of EV mode — another job for Flowcode. **NV**

■ FIGURE 9. A close-up of the Prius display showing the 99.9 mpg achieved.

References

Elektor February 2006 Easy CAN
Microchip **www.microchip.com**
Plug-in Prius Wiki group at: **www.eaa-phev.org/wiki/Main_Page**
Follow links to plug-in hybrids, then Prius.

The E-blocks Easy CAN bus pack includes a copy of Flowcode, two PICmicro multiprogrammers, two CAN bus boards, an LCD display, switch board, LED boards, and accessories.

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SMILEY'S WORKSHOP

AVR MICROCONTROLLER: C PROGRAMMING - HARDWARE - PROJECTS

by Joe Pardue

Get started now with this series! Joe's book & kit are available in our webstore at **www.nutsvolts.com**

PART 1:
Introducing the AVR C Programming Workshop Series

C programming and microcontrollers are two big topics, practically continental in size, and like continents, are easy to get lost in. Combining the two is a little like traipsing from Alaska to Tierra del Fuego. Chances are you'll get totally lost and if the natives don't eat you, your infected blisters will make you want to sit and pout. I've been down this road so many times that I probably have my own personal rut etched in the metaphorical soil, and I can point to the sharp rocks I've stepped on, the branches that have whacked me in the face, and the bushes from which the predators leapt. If you get the image of a raggedy bum stumbling through the jungle, you've got me right. Consider these workshops a combination roadmap, guidebook, and emergency first aid kit for your journey into this fascinating, but sometimes dangerous world.

I highly recommend that you get the book *The C Programming Language – Second Edition* by Kernighan and Ritchie, here after referred to as K&R. Dennis Ritchie (Figure 1) wrote C, and his book is the definitive source on all things C.

In Figure 1, Ritchie (inventor of the C programming language) stands next to Ken Thompson, original inventor of Unix, designing the original Unix operating system at Bell Labs on a PDP-11.

I have chosen to follow that book's organization structure in this series of workshops. The main difference is that their book is machine independent and gives lots of examples based on manipulating text, while these workshops are machine *dependent*, specifically based on the AVR microcontroller, and the examples are as microcontroller oriented as I can make them.

Why C?

Back in the dark ages of microprocessors, software development was done exclusively in the specific assembly language of the specific device. These assembly languages were character based 'mnemonic' substitutions for the numerical machine language codes. Instead of writing something like: 0x12 0x07 0xA4 0x8F to get the device to load a value into a memory location, you could write something like: MOV 22, MYBUFFER+7. The assembler would translate that statement into the machine language for you.

I've written code in machine language (as a learning experiment) and believe me when I tell you that assembly language is a major step up in productivity. But a device's assembly language is tied to the device and the way the device works. Assembly languages are hard to master and become obsolete for you the moment you change microcontroller families. They are specific-purpose languages that work only on specific microprocessors. C is a general-purpose programming language that can work on any microprocessor that has a C compiler written for it.

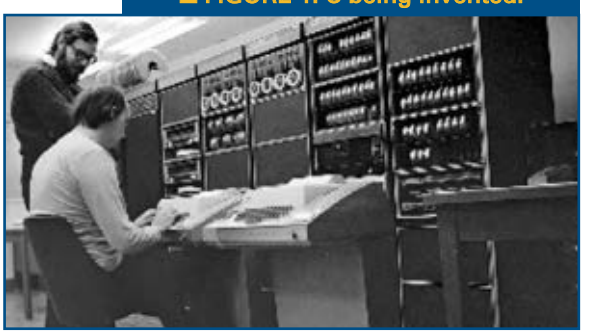
C abstracts the concepts of what a computer does and provides a text based logical and readable way to get computers to do what computers do. Once you learn C, you can move easily between microcontroller families, write software much faster, and create code that is much easier to understand and maintain.

Why AVR?

There are many excellent microcontroller families out there, but I chose the AVR because – among many reasons – it was designed with the C programming language in mind, has Flash memory that can be configured with a bootloader (more on all this later), and has the best user forum I've ever used: **www.avrfreaks.net**.

The AVR is fast, cheap, in-circuit

■ FIGURE 1. C being invented.



programmable, and development software can be had for FREE (really free, not crippled or limited in any way). I've paid thousands of dollars for development boards, programming devices, and C compilers for the other micros, but never again — I like free. The hardware used in these workshops — the Atmel AVR Butterfly — can be modified with a few components to turn it into a decent learning system and the needed components can be had for less than $40. You can't get a better learning system for 10 times this price and you can pay 100 times this and not get as good.

You will often stumble across arguments on the Internet as to which microcontroller or programming language is the 'best.' People take sides and soon a religious war breaks out. I don't want to enter that fray, so I'll just say that the AVR is the best microcontroller and C is the best programming language and if you don't believe me, you are bound for perdition — hallelujah and amen. *(Agreed! -Ed.)*

Workshop Goals

What I hope to accomplish with this series is to help you learn SOME C programming on A SPECIFIC microcontroller and provide you with enough foundation knowledge that you can go off on your own somewhat prepared to tackle the many kinds of microcontrollers and C programming systems that infest the planet.

Both C programming and microcontrollers are best learned while doing projects. I've tried to provide projects that enhance the learning process, but I've got to admit that some of the projects are pretty lame and are put in mainly to help you learn C syntax and methods.

I know how easy it is to get bogged down in all the detail and lose momentum on this journey, so we'll begin with a quick start guide and learn just enough to get our learning platform tools working — kind of a jet plane ride over the territory.

Quick Start Guide for the AVR Learning Platform

Software

AVR Studio — FREE and darn well worth it.

AVR Studio is provided free by the good folks at Atmel Corporation, who seem to understand that the more helpful free stuff they give developers, the more they will sell their microcontrollers. Actually, this software could cost hundreds and still be darn well worth it, but unless you just really like Norway, don't send them any money; they'll get theirs on the backend when you start buying thousands of AVRs for your next great invention. The workshop is based on version 4.14 and if you use a newer version you may find differences in it and our discussions. You can find AVRStudio at **www.atmel.com** under the AVR Tools & Software section: **http://atmel.com/dyn/products/tools_card.asp?tool_id=2725**).

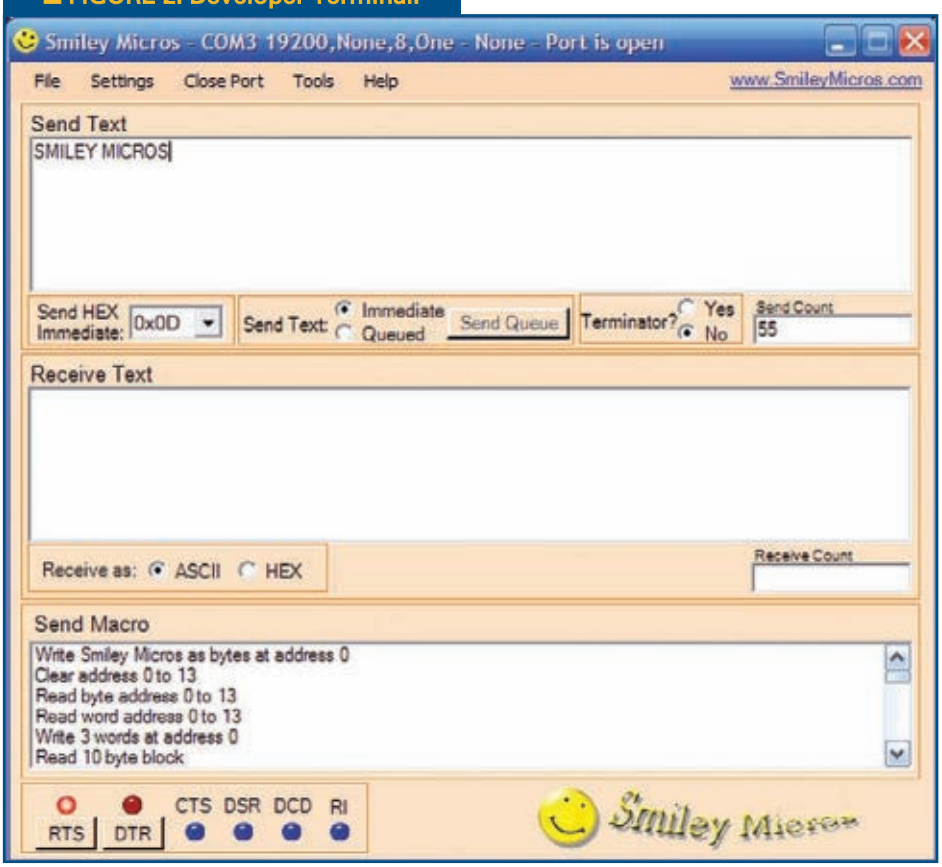
WinAVR — Oh, Whenever ...

WinAVR is a GCC compiler toolset for Windows that we will use in AVR Studio. We will use this package under the AVR Studio IDE that has a GCC plug-in that finds the WinAVR installation and adapts it to the IDE. You can find WinAVR at: **http://sourceforge.net/projects/winavr/**.

Developer Terminal

Figure 2 shows the PC terminal we will use to communicate with the AVR in our workshop. You can get the terminal installer and related documents from **www.smileymicros.com**. The source code in C# and Visual Basic .NET for this terminal is discussed in detail in the book *Virtual Serial Port Cookbook* (by me) and is available from **www.smileymicros.com** and *Nuts & Volts* (**www.nutsvolts.com**).

■ FIGURE 2. Developer Terminal.



Hardware

It is simply amazing what the Butterfly has built in:

- 100 segment LCD display
- 4 Mbit (that's 512,000 bytes!) data Flash memory
- Real time clock 32.768 kHz oscillator
- Four-way joystick, with center push button
- Light sensor
- Temperature sensor
- ADC voltage reading, 0-5V
- Piezo speaker for sound generation
- Header connector pads for access to peripherals
- RS-232 level converter for PC communications
- Bootloader for PC based programming without special hardware
- Pre-programmed demos with source code
- Built-in safety pin for hanging from your shirt (GEEK POWER!)
- Kitchen sink

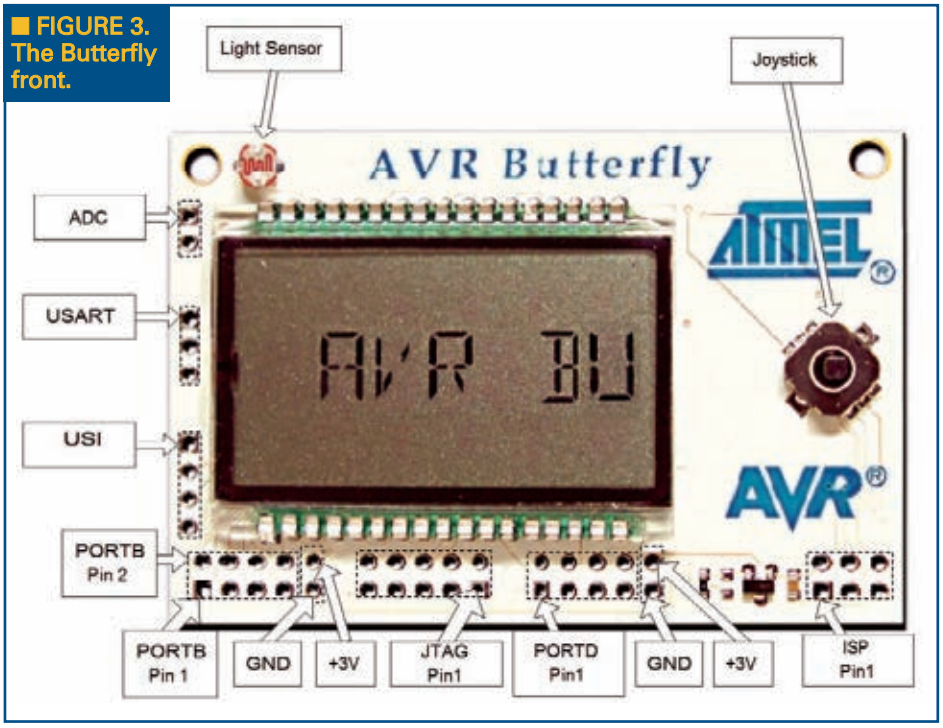
I mean this thing has everything (except a kitchen sink ... sorry). If anyone can find a learning platform with anywhere near this much for this price, I want to hear about it. If I seem to be raving a bit, get used to it. I do that a lot.

The AVR Butterfly box has instructions to show you how to use the built-in functions. Play with it now before you risk destroying it in the next step. I shudder to think how many of these things will get burned up, blown up, stepped on, and drenched in coffee. (And that's just me this morning.) After you've seen how it works out of the box, remove the battery and prepare to add components for our learning platform.

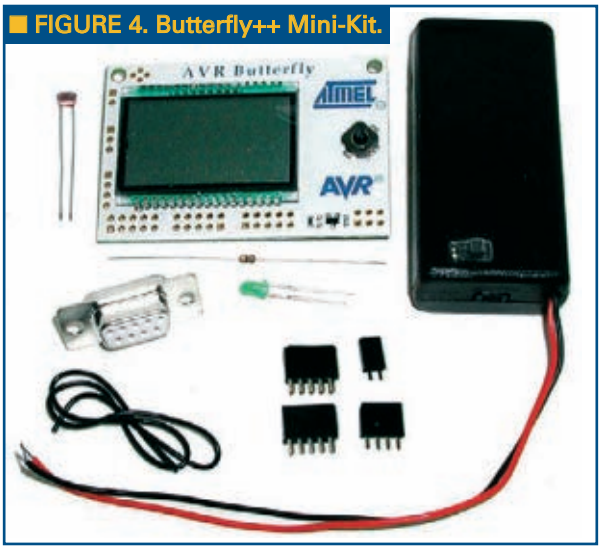
Butterfly++ Mini-Kit Construction

The Butterfly provides an excellent learning platform, but it can be even better with a few extra parts that Smiley Micros supplies in the Butterfly++ Mini-Kit. This kit includes a CdS light sensor, a DB-9 female connector and wires, and a two AA battery holder with power on LED and resistor.

■ FIGURE 3. The Butterfly front.

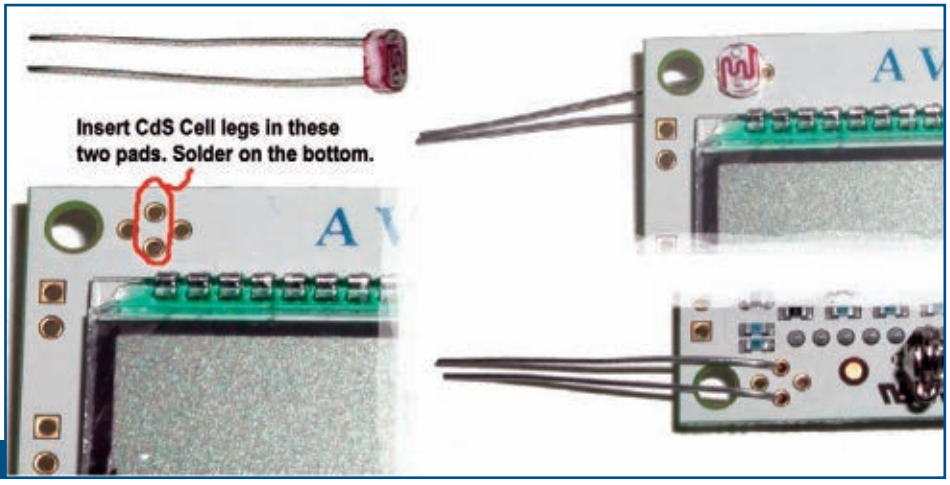


■ FIGURE 4. Butterfly++ Mini-Kit.



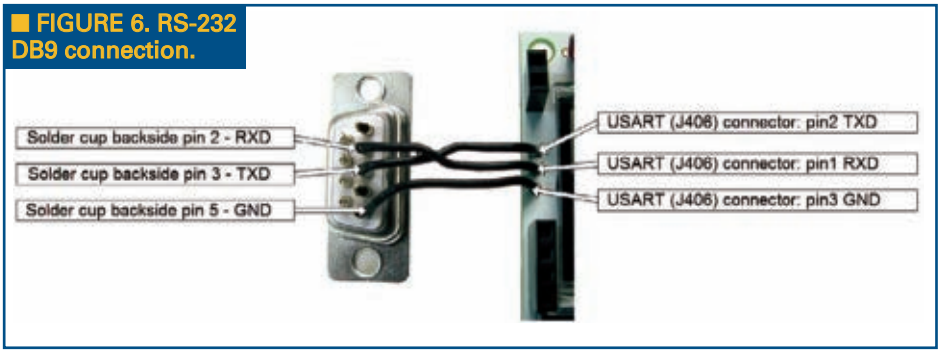
Adding a CdS Light Sensor

Atmel's AVR Butterfly no longer has a light sensor due to European RoHS compliancy considerations (don't get me started ...). The mini-kit



■ FIGURE 5. Butterfly CdS light meter.

■ FIGURE 6. RS-232 DB9 connection.



provides a suitable substitute component that the user must solder to the Butterfly to use the light sensor function. This sensor works with the existing Butterfly software.

The CdS light sensor is a device that has resistance proportional to the incident light. As a resistor, the device has no polarity so either leg can be inserted in the pads shown circled in red (see Figure 5). Seat the sensor snug to the top of the Butterfly, then solder the legs to the bottom and trim them just above the solder meniscus.

DB9 Female Connector and Wire

In order to communicate with a PC, the Butterfly must connect to a serial cable. The mini-kit provides the connector and wire to make the connection to a serial cable.

The Butterfly has built-in RS-232 converters for serial communication with a PC. Most serial cables will have a DB-9 male connector on the device side that will mate with the provided DB-9 female connector (calm down — it's technical).

Strip about 1/8 inch from the ends of each wire and then carefully solder them to the Butterfly and the DB-9 connector as shown in Figure 6. Notice that the upper wires in the picture cross. Be very careful to get this exactly according to Figure 6; about half the emails I get for problems turn out to be related to either incorrect wiring or poor soldering of this component.

Female Headers

Refer to Figure 7 to see the location of the ADC, USI, PORTB, and PORTD pads. Solder the two-pin header to the ADC pads; the four-pin header to the USI pads; and 2x5 headers to the PORTB and PORTD pads. Notice that Figure 7 shows a male header on the ISP pad; this is not included in the kit and won't be used for our work (maybe later).

AVR Learning Base Board

The AVR Workshop Learning Platform is built on a foamcore board that lives in a protective foamcore box. (Details for this construction can be found in *Smiley's Workshop 1 Supplement: AVR Learning Platform Foamcore Base and Box* at **www.nutsvolts.com**.)

You will need to carefully twist the ends of the battery box wires until they are straight, then soak them with solder so that it runs up under the insulation to make these wires strong enough to insert into the breadboard power bus. The red wire goes to the + red bus and the black wire goes to the – blue bus. Connect the two power busses with red and green wire and then put an LED with a 2.2K resistor on the breadboard. The resistor goes to the + power; the LED short leg goes to the – power. The LED and resistor are then connected on a breadboard strip.

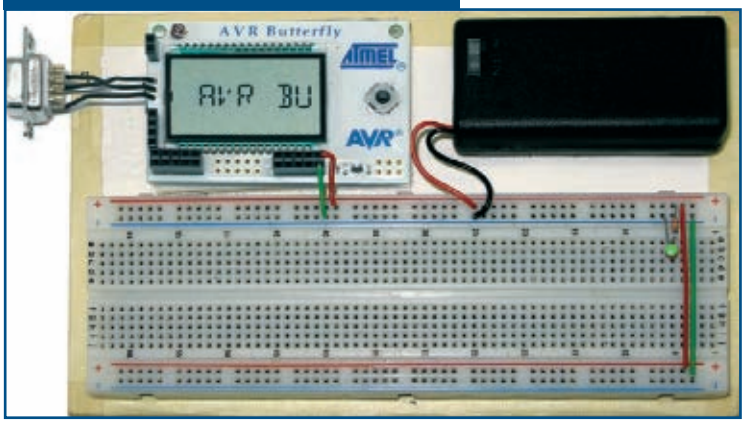
The Butterfly receives power from the bus as shown, the + red wire goes to the rightmost top of the header, and the – green wire goes to the rightmost bottom of the header.

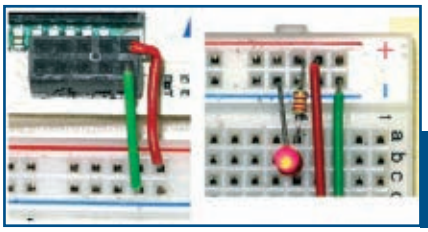
Test Your Connection Using Developer Terminal

Hook your Butterfly DB-9 connection to an RS-232 cable from a PC. If you use a USB-to-serial converter cable, you may have problems if the voltage levels are not robust. I've used several and have not had a problem.

Open Developer Terminal. You can read the user manual (I recommend: RTFM) by clicking the 'Help/Manual.' Click the 'Settings/Port' menu item to open the settings window. Select the RS-232 COM port that the Butterfly is connected to. Set the baud rate to 19200, data bits to 8, parity to None, stop bits to 1, and handshaking to none. You can test that your learning platform is

■ FIGURE 7. AVR Workshop Learning Platform.





■ FIGURE 8. Close-up of power connections.

Bill of Materials

ITEM	Supplier/PN
■ AVR Butterfly	Digi-Key/ATAVRBFLY
■ CdS LDR	Digi-Key/PDV-P9005-1
■ Two 2x5-pin header	Digi-Key/S7108
■ Four-pin header	Digi-Key/S71035
■ Two-pin header	Digi-Key/S71037
■ 3" Wire AWG 22	Jameco/36792
■ 2.2K ohm	Jameco/690742CG
■ Two-AA Bat. Box	Jameco/216119CG
■ DB-9 Female Ctr.	Circuit Specialists/DE-09S
■ Green LED	Circuit Specialists/ BAG-GREEN3MM

working okay by two methods. A simple test is to turn the power off on the Butterfly and then WITH THE JOYSTICK BUTTON PRESSED TO THE CENTER, turn the power back on. Now each time you press the joystick button to the center, you should see a series of question marks (????????) in the Simple Terminal receive window. This is the Butterfly bootloader wondering what the heck is going on.

Another test is to turn the Butterfly on and click the joystick up to get the LCD scrolling. Move the joystick straight down three times till you see 'Name,' then move the joystick to the right twice till you see 'Enter name.' Move the joystick straight down once and you will see 'Download name,' then push down the joystick center for a moment until you see 'Waiting for input.'

In Developer Terminal, make sure the 'Send Text: Immediate' radio button is checked. Type in your name, then in the 'Send HEX Immediate' dropdown box, select and click on 0x0D that tells the Butterfly you are finished sending characters. Your name should appear on the LCD.

This isn't easy and there are many opportunities to mess up along the way. Many folks get this going right away, but others seem to have fits getting over this hurdle, so I've provided a *Workshop 1 Supplement: Problems Communicating with the Butterfly* (on **www.nutsvolts.com**) to help you get past this point. Trust me, if you see the ????? or get your name scrolling on the LCD, you are over a major hump and subsequent workshops will be easier to get going than this step.

Well, that was a lot and we haven't really gotten started yet. Next month, we will look at the software side of the AVR Learning Platform and learn about the AVRStudio IDE and the WinAVR C compiler toolset. We'll write our first C program and create a set of Cylon Eyes in hardware. **NV**

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$6.00 each
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12V 1A CHARGER FOR LEAD-ACID BATTERIES

Input: AC 100-240 V 50/60 Hz.
Output: 12Vdc 1 Amp Max.
Charging Voltage: 13.8Vdc. Float charge Voltage: 14.8Vdc.
Table-top charger designed to charge 12V sealed lead-acid batteries. Should be good for up to 7Ah batteries. Output cord has a custom connector which will need to be removed to add your own connector or alligator clips. Because of improper storage many of these units have exterior blemishes but the units function fine.
$9.95 each
CAT# BC-100

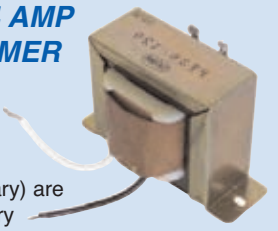
12 VDC AUDIO ALERT

Medium-loud high-pitched audio alert signal. Operates on 12Vdc (6-14Vdc). Plastic assembly 0.84" diameter x 0.51" high. PC pins on 0.6" centers.
CAT# SBZ-201
$1.25 each

3V LITHIUM COIN CELL WITH SOLDER TABS

Sanyo CR2016 3V 75mA coin cell with surface-mount solder tabs. Can be easily soldered to wires. Cell is 0.79" diameter x 0.07" thick. Battery circumference is protected with PVC insulation. **CAT# LBAT-51**
60¢ each
10 for 50¢ each
50 for 40¢ each

18 VOLT 1.4 AMP TRANSFORMER



18 Volt 1.4 Amp transformer. Removed from new equipment. Wire leads (primary) are 2" long. Secondary solder terminals have solder on them. 2" x 2.45" x 2.10" high. Mounting holes on 2.9" centers.
CAT# TX-1814
$4.85 each

24 VDC 6.5A POWER SUPPLY

Potrans #FS-15024-1M ITE Power Supply
Input: 100-120V 4A
200-240V 2.3A
Output: 24Vdc 6.5A
150W switching power supply. Enclosed metal vented case. 7.875" x 4.35" x 1.96". Over voltage, over current and temperature protected. LED output indicator. Adjustable voltage output. UL, CE, TUV.
CAT# PS-6524
$24.95 each

IR RECEIVER MODULE FOR REMOTE CONTROL

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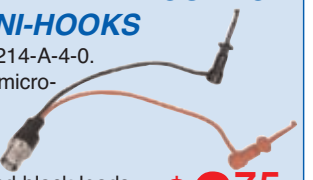
CAT# PCM-1
2 for $1.00

BNC FEMALE BREAKOUT TO MICRO-MINI-HOOKS



Mueller # BU-5214-A-4-0. BNC female to micro-mini-grabbers. Rating 300 VRMS 5 Amps. Red and black leads.
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$6.75 each

MINI OPTICAL SCROLL MOUSE

Miniature optical mouse is ideal for use with laptop computers. Plugs into USB port. Works on a variety of surfaces. Provides more precise control than touch pads. Small (about half the size of a standard mouse) and portable.
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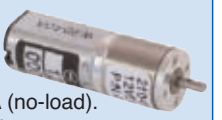
$8.75 each

12 VDC 58 RPM MINI-MOTOR



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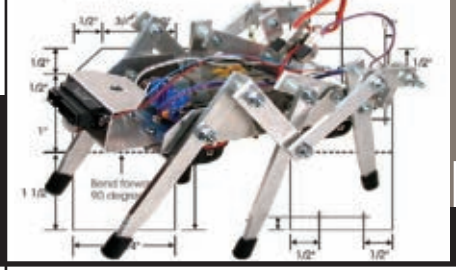


■ BY VERN GRANER

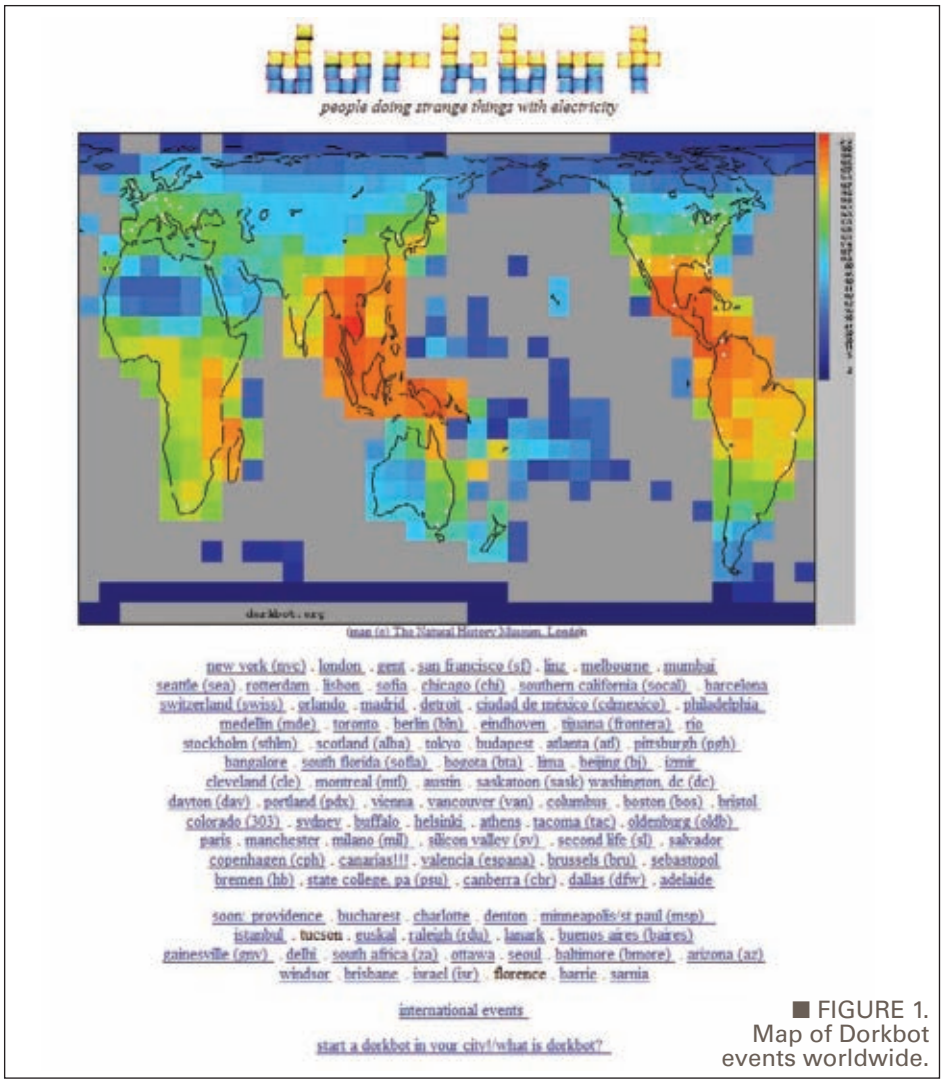
DORKBOT
People Doing Weird Things With Electricity

SO, YOU'VE BEEN WORKING ON YOUR electronic masterpiece for a few weeks (months?) and it's finally finished, so ... now what? Where can you go to show off your little beauty, the child of your imagination, the fruits of your labor? How about Dorkbot?

Dorkbot's motto is "People doing strange things with electricity" and from what I've seen, I'd say that's a very accurate description. Founded by Douglas Repetto of Columbia's Computer Music Center in the fall of 2000, Dorkbot has spread across the world providing a framework for display, collaboration, and celebration of all things tech (Figure 1).

On a sultry, summer evening in June 2006, David Nunez, Rodney Gibbs, and Rich LeGrand pulled off the first Dorkbot Austin "Cafe Mundi" — a cute and quirky East Austin restaurant and hangout. When I arrived, there was a video projector pointed at a big screen on one side of the parking lot and a small PA system for the presenters to use. In a matter of moments, I got a general impression of what Dorkbot Austin was all about. There were projects and people, devices and drinks, music and madness. It was a contagious carnival atmosphere with artists, electricians, programmers, musicians, the curious, and the chaotic all coming together to show and tell about their creations while networking with other self-confessed "dorks" (Figure 2).

At the time of this writing, there have been 15 such events in Austin since that first summer night, averaging a little over one every other month. Most of the events have been at Cafe Mundi; the exceptions being the South By Southwest (SXSW) festival events that were held in downtown Austin and one special event held at the Austin Children's Museum. Though most of the events



■ FIGURE 1. Map of Dorkbot events worldwide.

■ FIGURE 2. Dorkbot Austin at Cafe Mundi.

have been privately organized and funded, some have been sponsored by such big names as South by Southwest (SXSW), *Make Magazine*, Amaze Entertainment, and the International Game Developers Association (IGDA) (Figure 3).

Due to the nature of a Dorkbot event, the main facilitators have changed as new folks become interested and some of the early movers and shakers have moved on to other projects. Though David Nunez and Rich LeGrand are no longer working with Dorkbot Austin, the current Dorkbot Austin crew of Rodney Gibbs, Luke Iseman, Chase Hammock, and Nick Pietraniec have stepped in to make sure the event lives on.

I did get a moment to chat with

■ FIGURE 3. Dorkbot poster by Noel Waggener; **subculturepress.com**.

THERE'S NO DORKBOT IN YOUR CITY? MAYBE YOU SHOULD START ONE!

Some things to consider:

What is Dorkbot, exactly? Each Dorkbot event is different and is driven by the needs and interests of people in the local community. But generally, the main goals of Dorkbot are: to create an informal, friendly environment in which people can talk about the work they're doing and to foster discussion about that work; to help bring together people from different backgrounds who are interested in similar things; and to give us all an opportunity to see the strange things our neighbors are doing with electricity. Dorkbot isn't really a forum for formal artist talks or lectures, but rather a chance for diverse people to have friendly conversations about interesting ideas. The organizers of Pixelache 2008 asked Douglas to talk about Dorkbot's "organizational strategy." Here's what he had to say:

■ *Frequency:* How often will you hold meetings? Some Dorkbots have meetings every month, others just a few times a year. It's a lot of work putting the meetings together, and in smaller cities it can be difficult to schedule enough speakers. You don't want to burn out!

■ *Locale:* If you are in a smaller city or town, you might want to consider collaborating with people in other nearby cities/towns. Maybe the Dorkbot meeting can travel to a different location each month, or maybe you can all pool your resources for a couple long-form meetings each season.

■ *Venue:* Is there a place to hold the meetings? It can be very convenient to have the meetings in the same place each time. Often, an art gallery or performance space will be willing to donate their facilities for the occassional meeting. If you know someone connected to a university, you may be able to get a space through them. It doesn't have to be a fancy space!

■ *Equipment:* Do you have access to presentation equipment? At the least, you'll probably need a video projector, a small sound system, and a network connection. A laptop computer can also make things easier on the presenters. As with the venue, it's best if you can use the same equipment at each meeting. It can be very stressful trying to track down a video projector the day of a Dorkbot meeting! Often, the venue you use will have A/V equipment you can borrow.

■ *$$$:* Dorkbot is a non-$-oriented organization. Dorkbot meetings are generally free events, so you need to be careful about spending lots of money to produce them! Several Dorkbots sell beer and/or food at the meetings to help cover their costs. Make sure you talk to the venue before selling anything. **Dorkbot.org** donates web space, email lists, etc., to the local Dorkbots, so there is no administrative cost associated with setting up a new Dorkbot.

■ *Meeting Format:* Dorkbot meetings are rather informal. There are usually two or three presentations (about 20-30 minutes each) per meeting and sometimes very short "lightning" presentations from audience members. The specific format is up to each organizer to decide. You'll probably have to play with your format for a few meetings until you find something that works well in your context. One thing to keep in mind is that the Dorkbot format works best for informal, conversational presentations on a particular work or topic, rather than formal artist talks or lectures on a body of work. Thirty minutes isn't much time, so focused presentations work best.

What happens next?

If you think you'd like to start a Dorkbot in your city, contact Douglas at douglas@dorkbot.org for more information.

■ FIGURE 4. SXSW Dorkbot in downtown Austin drew a huge crowd. (*Photo by James Delaney.*)

■ FIGURE 5. View from the stage at a Dorkbot Austin event.

Nick Pietraniec about Dorkbot to get his take on things. Nick comented, "I think fundamentally our goal is to provide a forum for our community to meet, collaborate, socialize, brainstorm, and show off their work — this is probably a common mantra for most Dorkbot communities, but there's no central organization or mission. If you go to an event in London, Montreal, South Africa, or Dallas — it might look completely different."

When I asked him what it was like running a Dorkbot event, he responded, "Actually, 'running' probably isn't really the proper term. We're more 'facilitators' in that we simply solicit for presenters, coordinate the venues. When we reach a critical mass of folks interested in showing off their work, we send out the announcements, get the gear, and head for the site."

Though I haven't had the pleasure of attending a Dorkbot outside of Austin, the ones here have been a LOT of fun and are both very well attended and received. At the SXSW Dorkbot Austin, there was a huge crowd of people who came together to talk about tech, show off their electronic feats, and let their inner dork shine (Figure 4). Attendees are encouraged to bring finished items, parts and pieces, or even just plans or sketches. It's a good place to hang out and to network with other folks that have similar interests.

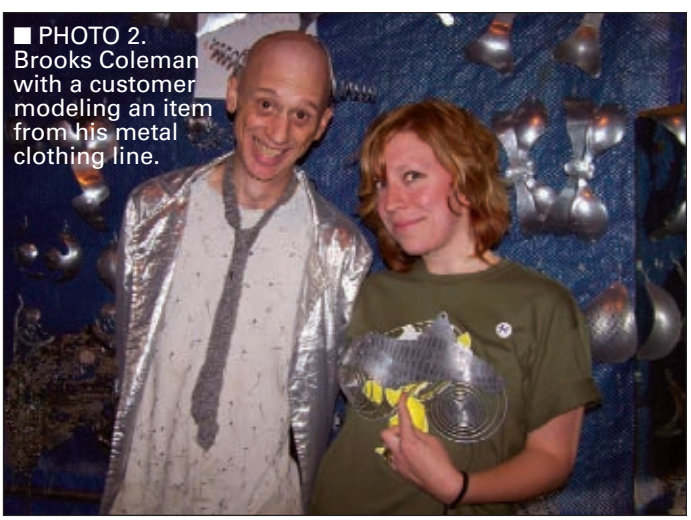
Experimental music, strange contraptions, and prototype systems breaking down on stage accompanied by small gouts of blue smoke make for an exciting day. Even the projects that flame out are enthusiastically applauded!

So, what is attending a Dorkbot like? To me, it felt something like a trade show — rock concert — nerd party — ham fest — science fair all at the same time. There's usually adult

■ PHOTO 1. Nic Graner sports aluminum "slit glasses" by Brooks Coleman.

■ PHOTO 3. Glamor Girl — a mixed-media EL wire lighted sculpture by Brooks Coleman. (*Photo by James Delaney.*)

■ PHOTO 2. Brooks Coleman with a customer modeling an item from his metal clothing line.



■ FIGURE 6. RoboSpinArt demo board for software development and proof of concept testing.

■ FIGURE 7. Vern Graner glues a servo motor back on the RoboSpinArt demo board moments before show time.

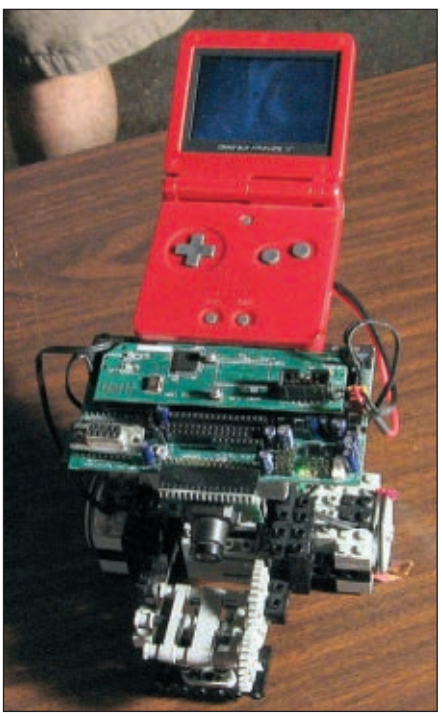
■ FIGURE 8. Kym Graner operating the RoboSpinArt machine at Dorkbot. *(Photo by James Delaney.)*

beverages being consumed (which certainly adds to the festive nature of the event!) and kids running around having fun and beeping/zapping/blinking things everywhere (Figure 5). At the Austin shows I've attended, the "master of chaos" David Nunez was usually scampering about trying to make sure the next presenter was ready to go, introducing each new segment, and generally making sure everyone has what they need and has a good time.

In addition to being just a heck of a lot of fun to attend, Dorkbot has been a wonderful venue for The Robot Group to test out and demonstrate some of our newest designs. It has provided a sympathetic and knowledgeable audience for some of our more notable projects such as the RoboSpinArt machine (*Nuts & Volts*, January '08) and the Power Flowers (*Nuts & Volts*, July '08).

The first time I presented a concept project, all I had to show

■ PHOTO 4. A Gameboy SP powers a small LEGO-based robot.



Q&A ABOUT SELF-ORGANIZATION: DORKBOT AN INTERVIEW WITH DOUGLAS REPETTO

"I generally try to stress that each Dorkbot is autonomous and some of them are quite different in form and spirit from one another. So, it's difficult to make very general, overriding statements. Of course, journalists live for general, overriding statements, so sometimes it's a hopeless cause ..."
—Douglas Repetto, Dorkbot creator

What are the aims of the project you are involved in?

Dorkbot has only a motto: "People doing strange things with electricity." Different groups have interpreted the motto in different ways. When I thought of the motto, I purposely made it broad and inclusive so that it would interest many different kinds of people doing different kinds of things. Artists, inventors, scientists, engineers. The exciting thing to me is to learn about strange things that creative people are doing around the world, with no regard for genre, style, school of thought, area of expertise, etc.

How is the project organized?

It is mostly dis-organized. We have a server at the Computer Music Center at Columbia University (where I work). That hosts many of the Dorkbot websites (but not all). We also run many (but not all) of the mailing lists from the server. Other than that shared web resource, each Dorkbot is more or less completely autonomous. Very early on when there were just three or four Dorkbots, I decided that the best thing to do would be to give up any control I might have over the other organizations. At first, I was worried about other people using the name in ways I didn't like, or organizing meetings in ways I didn't agree with, but I quickly realized that if I really wanted to be inclusive I would have to let go and let other people find their own way. We have a Dorkbot-overlords mailing list, and we exchange occasional messages between the various people who run all the different Dorkbots around the world. But even that is very low volume. I think that the main thing that has given Dorkbot an identity of sorts is the website and the motto. People see that it is not super self-serious. That it is informal and friendly. That it is about creativity. I think that is enough.

The above interview excerpt courtesy of "Pixelache 2008 Helsinki." To read the rest of the interview, point your web browser to ***ttp://tinyurl.com/3sewrq****.*

■ PHOTO 5. "Professor Conrad" (a.k.a., Marvin Niebuhr) adjusts one of the instruments from his Screaming Babyhead Band. (*Photo by James Delaney.*)

■ PHOTO 6. The SanDraw kinetic sculpture by Rick Abbot and Paul Atkinson. (*Photo by James Delaney.*)

was a bunch of sketches and a development board (Figure 6) for the RoboSpinArt machine that was hastily glued back together moments before I was scheduled to talk (Figure 7). When I was done speaking, I got a hearty round of applause and was then peppered with questions about the demo board and how I envisioned the final project taking shape. When we brought the finished machine back for a later show (Figure 8), the crowd was very enthusiastic and many folks came up to ask about details of the mechanisms and how we had solved some of the problems mentioned in the first presentation.

The fact that the folks behind Dorkbot don't really run Dorkbot so much as set the stage for it to happen makes for an interesting dynamic since there are none of the typical trappings of a managed event. The folks who show up are the ones who get up and talk. The presenters swap places with the audience and there is plenty of opportunity for interaction and collaboration. In order to be featured at Dorkbot, all you have to do is sign up via email and tell the Dorkbot folks what you'd like to do — kinda like a grown-up

RESOURCES

- Dorkbot: **http://dorkbot.org**
- Dorkbot Austin: **www.dorkbotaustin.org**
- Cafe Mundi, Austin, TX: **www.cafemundi.com**
- The Robot Group: **www.TheRobotGroup.org**
- The Thereping: **www.thereping.com**
- The RoboSpinArt Machine: **www.robospinart.com**
- PingPongPrinter: **www.youtube.com/watch?v=8Ep5OC3E02I**
- Poster artwork by Noel Waggener: **www.subculturepress.com**
- Workbench Design Contest: **http://forum.servomagazine.com/viewtopic.php?t=8180**

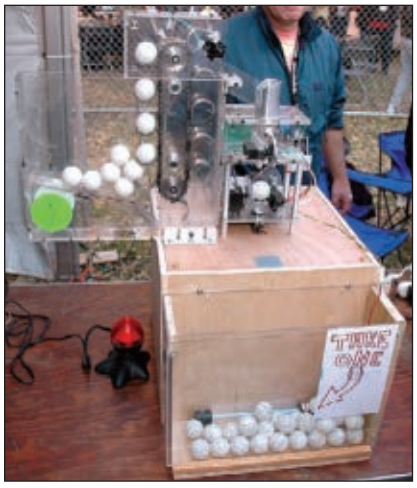
■ PHOTO 7. A ceramic, wood, and light bulb sculpture by Denise Scioli.

■ PHOTO 8. "Gator Girl" animatronic sculpture in aluminum by Brooks Coleman. (*Photo by James Delaney.*)

■ PHOTO 9. Paul Atkinson checks out the POV display at Dorkbot SXSW.

■ PHOTO 10. Bob Comers robot made from PVC pipe and recycled "kiddie car" motors and wheels.

■ PHOTO 11. Sami Graner interacts with a "Biomechanical" by "Professor Conrad" (a.k.a., Marvin Niebuhr).



■ PHOTO 12. The Ping Pong Printer with its new ball-feed hopper by Rick Abbot.

version of "show and tell." You would think this free-form method of (non? dis?) organization would lead to chaos, but every Dorkbot I've attended has run surprisingly smooth.

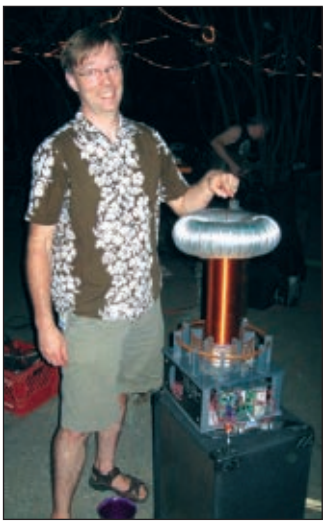
If this sounds like something you'd like to do, but there isn't a Dorkbot scheduled in your city, you can start your own Dorkbot. All you need to do is send an email to Douglas Repetto (his email address is on the main **Dorkbot.org** website). He'll set you up with a mailing list and a link on the main site, and you're off! If there is a Dorkbot near you, you should make a point of at least attending if not signing up to present something. What better way to meet folks than to stand up before a small crowd of other tech geeks just like yourself and talk about your project?

I'd like to close this month by thanking everyone who has sent in an entry for the Workbench Design Challenge (see the Resources section for a link to the contest details on the *Nuts & Volts* web forum). I look forward to handing out the prizes! And, if you happen to find yourself at Dorkbot Austin, look around for me there.

Otherwise, you can always reach me via email at vern@txis.com if you have any questions or comments. **NV**

I'd like to say a special thank you and goodbye to one of the founders of Dorkbot Austin, David Nunez. A good friend and long time collaborator with The Robot Group, we wish him Favorable Chance and Deity Velocity in his endeavors out east!

■ PHOTO 13. Edwin Wise and his homebrew Tesla coil.



■ PHOTO 14. Gray Mack with his balloon-based light sequencing system.

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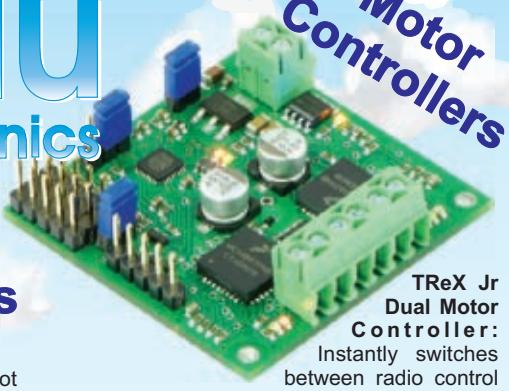

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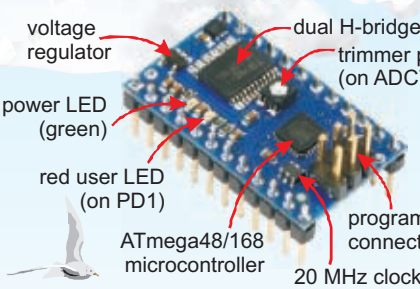

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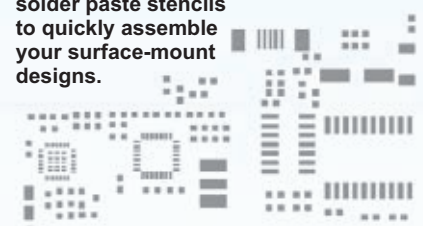

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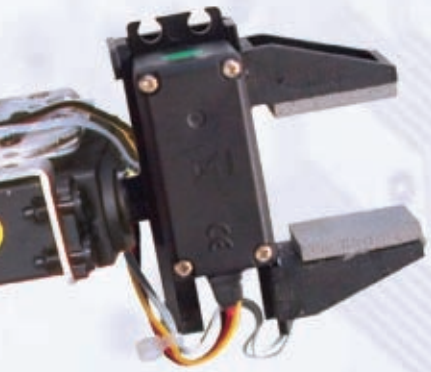

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BY LOUIS E. FRENZEL W5LEF

TEN THINGS YOU MAY NOT KNOW ABOUT BLUETOOTH

Making the wireless everywhere movement come true

BLUETOOTH IS A VERY FAMILIAR NAME THESE DAYS if you have a cell phone or laptop. It is a wireless technology that has been around a while and probably can be credited as the start of a whole boat load of short-range wireless technologies. But even if you have heard the name, you may not really know all about it. Here are 10 facts that will update your knowledge of this hot wireless method.

BLUETOOTH IS 10 YEARS OLD

I am not kidding. It was back in 1998 that this wireless method was conceived by European telecommunications giant Ericsson. Ericsson along with four other companies selected the name Bluetooth and formed the Bluetooth Special Interest Group (SIG) to develop the technology. Now it is the most widely used short-range wireless technology.

BILLIONS SOLD! THERE ARE MORE BLUETOOTH RADIOS ON THE PLANET THAN ANY OTHER

Cambridge Silicon Radio — the leading Bluetooth chip supplier — shipped over 600 million chips in 2007 and is expected to ship about a billion more this year. That's just one supplier. The total number of chips buried in other products is well over several billion. The reason for such high volume is that the number one use of Bluetooth is to implement the wireless headset in cell phones. That means two Bluetooth chips for each: one in the handset and the other in the ear piece. Most cell phones have this feature today. And since cell phones sell in the one billion per year range, you can see how Bluetooth got to be number one. There are dozens of other uses, as well. ABI Research — a market information company — predicts that about 2.4 billion Bluetooth-enabled products will ship in 2013.

THE BLUETOOTH SIG MANAGES THE STANDARD

The Bluetooth SIG is the organization that develops the technology, establishes the standard, tests for interoperability and certification, and promotes the brand. It is a consortium of over 10,000 companies. And their work is on-going. For more details on this wireless success story, go to **www.bluetooth.com** or **www.bluetooth.org**.

BLUETOOTH SPECIFICATIONS AND FEATURES ARE CONTINUOUSLY UPDATED

Bluetooth is a short range technology that operates in the unlicensed 2.4 GHz industrial-scientific-medical (ISM) band. It has to co-exist with Wi-Fi LANs, cordless phones, and microwave ovens, to mention just a few services that also use this band. But it does pretty well with a range up to about 30 feet. The basic output power is 1 mW (0 dBm) but you can use two other power levels for longer ranges: 2.5 mW (4 dBm) and 100 mW (20 dBm).

Bluetooth uses a very robust radio technology called frequency hopping spread spectrum. It chops up the data being sent and transmits chunks of it on up to 75 different frequencies. In its basic mode, the modulation is Gaussian frequency shift keying (GFSK). It can achieve a gross data rate of 1 Mb/s. A more recent upgrade called Enhanced Data Rate (EDR) uses π/4-DQPSK that gives a data rate to 2 Mb/s and 8DPSK that will deliver up to 3 Mb/s.

BLUETOOTH PROFILES DEFINE THE APPLICATIONS

The Bluetooth standard defines not only the radio interface just described but also a comprehensive data transmission protocol. The protocol spells out how the data is packaged into packets, transmitted, and received. It is a flexible protocol that can be adapted to almost any type of data. The protocol is implemented in a software stack that defines the sequence of operations. While designers are free to create their own application on top of the Bluetooth protocol, it is a difficult process.

To make Bluetooth more attractive to a wider range of applications, the SIG has developed a wide range of Profiles. These are special software packages designed to implement the most popular applications. The Profiles define the applications. Among the Profiles available are one for cell phone headset, wireless headphones, wireless printer to PC connections, human interface devices (keyboards, mouse, etc.), automotive hands-free kits, cordless phones, fax machine links, video streaming, and a whole bunch of others. The Profiles speed up and simplify the application development and help ensure compatibility of similar products. One popular application is the use of Bluetooth in the hand controllers for the Nintendo Wii game console.

LOW POWER VERSION OF BLUETOOTH NOW AVAILABLE

A couple of years ago, Nokia — the leading cell phone maker — developed a low power wireless technology similar to Bluetooth. Nokia joined with several other companies to develop this technology into a standard. It was called WiBree and a consortium was founded. Last year, the WiBree group merged with the Bluetooth SIG to further develop this method. It uses a simpler version of Bluetooth to significantly cut operating power so that wireless devices can be operated from coin batteries like those in wrist watches. The goal is to create wearable wireless devices in watches, running shoes, and medical monitoring devices. Many of the newer Bluetooth chips contain the standard Bluetooth transceiver in addition to a low power (LP) transceiver.

HIGHER SPEED VERSION OF BLUETOOTH WILL USE ULTRA WIDEBAND (UWB)

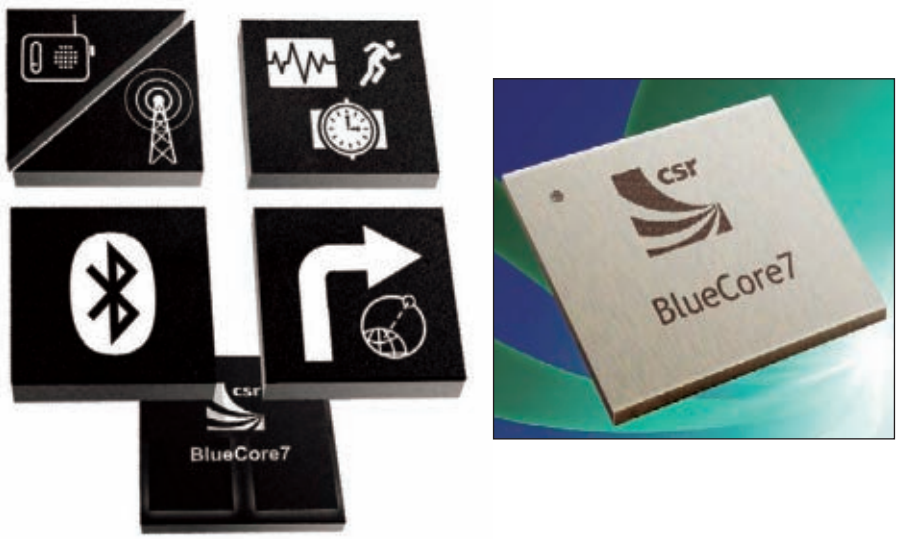
The fastest version of Bluetooth is called EDR and can transmit at a rate up to 3 Mb/s. That is fast enough for most audio and low speed applications and that rate has certainly not limited Bluetooth's adoption. But for faster data transfers like downloading photos from a digital camera or transmitting video, a faster radio technology is needed.

Recently, the Bluetooth SIG adopted the WiMedia ultra wideband (UWB) radio technology. This wireless standard developed by the WiMedia Alliance can transmit data at a rate to 480 Mb/s over several meters. It uses orthogonal frequency division multiplexing (OFDM) in the 3.1 to 4.7 GHz range. Its main use so far has been a very successful wireless USB cable replacement. The Bluetooth SIG is developing a version of this standard that will carry the Bluetooth protocol and profiles but with the ability to transmit at rates up to the 480 Mb/s range over short distances. The Bluetooth version will operate above 6 GHz and is expected to be available in 2009.

BLUETOOTH TEAMS UP WITH WI-FI TO BOOST DATA RATES

The Bluetooth UWB effort is on-going but in the meantime, the Bluetooth SIG has adopted another way to speed up some transmissions. Specifically, it has created a way to let the Bluetooth protocol and profiles operate over a Wi-Fi radio if present. Wi-Fi is the wireless local area network (WLAN) standard of the IEEE, also known as 802.11. It is available in several versions: a, b, g, and n. Bluetooth radios will incorporate what is called a generic alternate MAC/PHY. MAC means media access control and PHY means physical layer interface. The MAC part of the radio defines how the data is packaged and transmitted while the PHY defines the radio interface like RF and modulation. This alternate MAC/PHY will be able to

■ FIGURE 1. The Cambridge Silicon Radio BlueCore7 is the lates generation of Bluetooth transceivers designed for cell phones and other applications. The chip itself is a tiny 3.2 x 3.6 mm. It contains four separate radios as depicted in the diagram, a conventional FM receiver with RDS, a GPS satellite navigation receiver, a low power Bluetooth transceiver, and a standard Bluetooth transceiver with EDR.



dynamically select either the Bluetooth radio or the Wi-Fi radio based on the need for faster transmission, or not.

BLUETOOTH IS SUCCESSFUL DESPITE THE COMPETITION

If you follow the wireless field at all, you know that there are many other wireless standards and methods out there. Most of the short-range technologies are competitive with one another in some way. Yet even with the competition, Bluetooth has carved out a healthy niche, if you can call billions of units sold a niche. Bluetooth had a head start on most of the other technologies and that is partially the reason Bluetooth is so well entrenched. While Bluetooth applications may overlap a bit with Wi-Fi and UWB, the SIG was smart to adopt these technologies to support Bluetooth in some applications. So you can almost write off Wi-Fi and UWB as competition. That leaves ZigBee as the only clear competitor.

ZigBee is that technology developed around the IEEE 802.15.4 standard that targets industrial control, building monitoring and control, remote meter reading, and other applications where sensor outputs are observed and used to initiate controls or record the data. It uses very low power so a ZigBee transceiver can operate for months or even years on a coin battery. ZigBee's big claim to fame is its ability to form mesh networks among hundreds of radio nodes. While Bluetooth has some limited networking capability, it was not designed for mesh networks. So, while the two technologies may butt heads in a few applications, for the most part each has its own sphere of uses.

The only other short-range technology that may come close to Bluetooth in volume is ISM band radios that operate in the 315, 433, and 915 MHz range. These are used in garage door openers, remote keyless entry devices for vehicles, tire pressure monitoring, remote thermometers, and toys. These devices are usually much simpler so do not need the sophisticated protocol of Bluetooth.

WHO MAKES BLUETOOTH CHIPS?

As I mentioned earlier, the leading Bluetooth chip company is Cambridge Silicon Radio (CSR). They were one of the first vendors and they still maintain a wide lead over the others. Other Bluetooth chip companies are Broadcom and Texas Instruments. Figure 1 shows CSR's latest transceiver chip which incorporates the latest Bluetooth EDR radio, a low power transceiver, a GPS satellite navigation receiver, and a standard FM radio all in one. It is expected that this chip will save lots of space and power when built into cell phones. **NV**

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■ BY FRED EADY

UP THE LOGIC FOOD CHAIN

I was a totally analog teenager. My interests then were centered on tube-based stereo equipment and tube-based guitar amplifiers. I was fat, dumb, and happily analog until I ran across a copy of the GE Transistor manual in the literature section of a local electronics parts store. I had to have it. Everything "electronic" I was reading about at the time was telling me that vacuum tubes were on their way out and transistors were the thing of the future. At that time, hand-held calculators were becoming popular and as far as I was concerned, they were "magical" devices that I would never ever understand at the electronic level. So, in an attempt to embrace transistor technology, everything "tube" was replaced with a comparable "transistor" device.

My guitar amp and stereo projects became transistorized. I even started to wonder about what was inside of those "magical" calculators. As I transitioned from teen to adult, building stereo equipment and guitar amps gave way to transistor and IC-based logic projects. The transition was complete. Well, not quite.

These days, my guitar amplifiers are all tube-based. However, I'm still "solid-state" when it comes to logic. In past Design Cycle columns, we've explored the nuances of many a microcontroller. We have also recently delved into the world of CPLDs. It's time to move up another step on the logic food chain. In this installment of Design Cycle, we are going to tackle the FPGA.

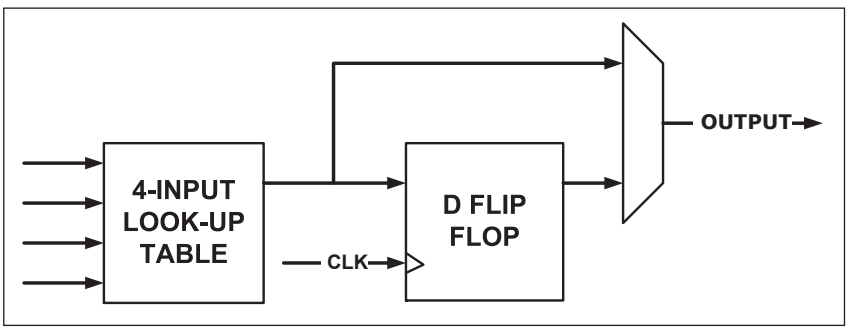
FPGA 101

FPGA is short for Field Programmable Gate Array. In reality, an FPGA is actually a programmable solderless breadboard populated with interconnectable logic blocks. An FPGA differs from a CPLD (Complex Programmable Logic Device) in that the FPGA contains considerably more logic gates. Also, an FPGA may contain memory and high-level embedded building blocks such as adders and multipliers.

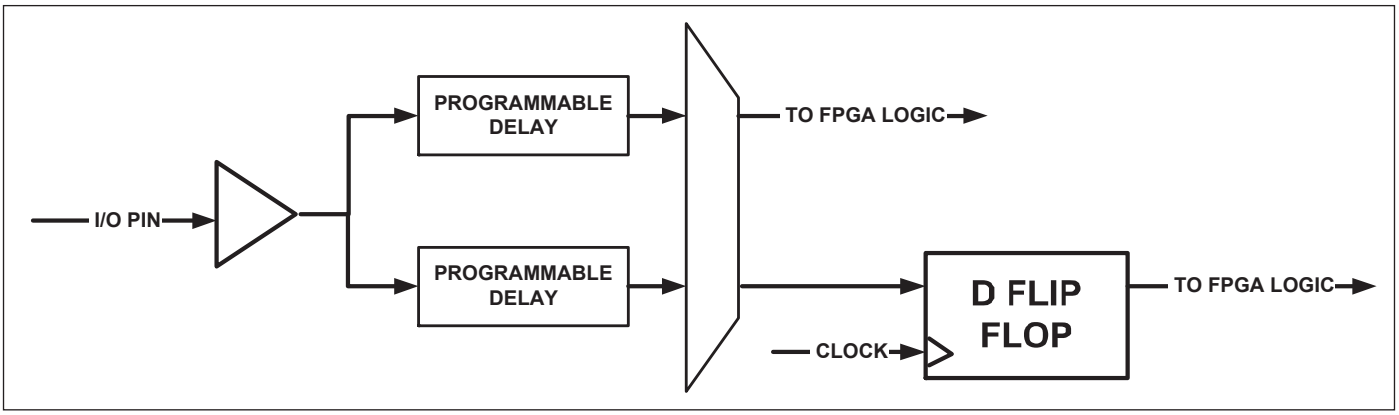
CPLD logic is based on sum-of-product logic arrays that interconnect and feed clocked registers. FPGA logic is rooted in LUTs (Look-Up Tables) such as the one you see in Figure 1. Basically, we can configure the LUT to be any type of logic gate with up to four inputs. The clock signal in Figure 1 would normally be provided by the FPGA's internal clock routing system. Depending on our desired logical function, the LUT infrastructure allows us to pass our logic output through the D flip-flop for registered operation or bypass the D flip-flop for an unregistered output operation.

The power of the LUT comes in numbers. The FPGA fabric allows for interconnection of a large number of LUTs. Using the FPGA's internal interconnection fabric allows us to combine the logic contained within a large number of LUTs to generate complex logical operations.

In this spin of Design Cycle, we will be basing our FPGA designs on Xilinx FPGAs. Thus, the generic concept of a LUT is similar to what Xilinx calls a CLB (Configurable Logic Block). A CLB is made up of function generators, registers, and reprogrammable routing controls. Equating a



■ FIGURE 1. If we choose to use the D flip-flop output, the output of this LUT is registered. Bypassing the D flip-flop all together results in an unregistered output signal.



■ FIGURE 2. From a user/programmer standpoint, these FPGAs aren't as complicated as one might think. Buffers, clocks, multiplexers, and latches are common logic building blocks that I'm sure all of you understand. What you don't see here are the pull-up/pull-down and ESD components at the input buffer input.

CLB to Figure 1 illustrates the CLB concept.

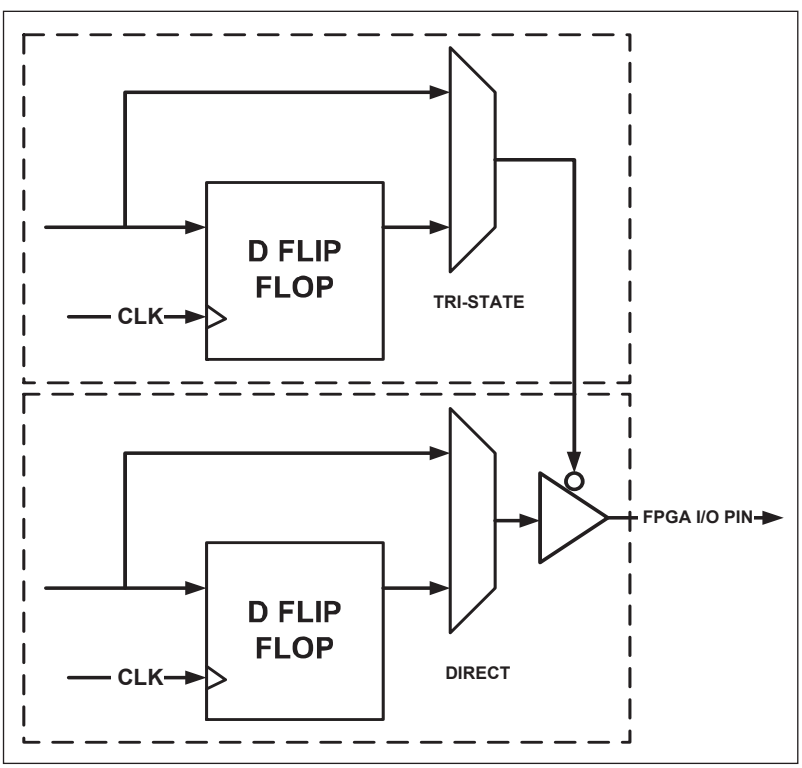
Translating the Xilinx speak to Figure 1 graphics, the Xilinx "function generators" are actually the look-up table. In terms of an FPGA, a register is synonymous with a latch or a flip-flop. In the case of Figure 1, the Xilinx register is our LUT's D flip-flop. Reprogrammable routing control is a fancy way of saying multiplexer. Our LUT's reprogrammable routing control is represented in Figure 1 by the two-input multiplexer at the LUT output.

CLBs are the physical foundation that all Xilinx FPGA designs are built upon. All of the software-generated logical functions are implemented by CLBs. In the Xilinx FPGA we will be working with, a CLB is a wee bit more complex than our simple LUT in Figure 1. A CLB is made up of four interconnected slices. Each slice consists of a pair of LUTs and two dedicated storage elements that can act as flip-flops or latches. One pair of LUTs supports logic and memory functions within the slice. The remaining LUTs in the slice service logic only. This logical arrangement of slices allows the LUTs to be used as 16x1 memory or as 16-bit shift registers.

We will be working with two Xilinx Spartan-3A FPGAs: the XC3S700A and the XC3S50A. The plan is to cut our FPGA teeth with the larger 700A and design our own FPGA hardware with the smaller 50A. To give you a feel for the FPGA size difference, the BGA-packaged 700A contains 1,472 CLBs and 700,000 system gates while the much smaller 144-pin 50A has but 176 CLBs and 50,000 system gates. We're going with the smaller Spartan-3A FPGA for our hardware design because it is housed in a solder-friendly 144-pin TQFP package.

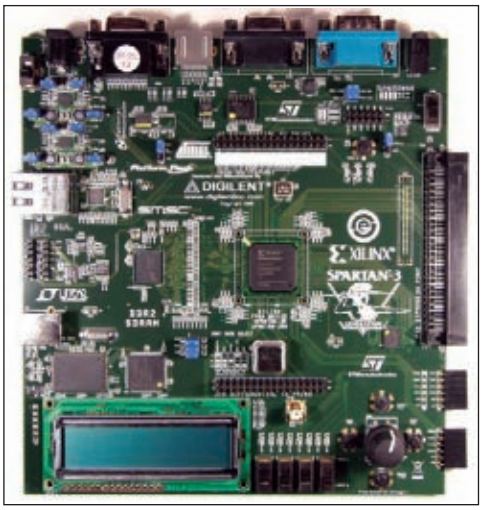
The whole idea of using an FPGA in an electronic circuit of our design would be null and void if we were unable to access the internal logic of the FPGA. The physical I/O pins of our Xilinx FPGAs are all tied internally to IOBs (Input/Output Blocks). Think of an IOB as a programmable unidirectional or bidirectional I/O interface to the FPGA's logic blocks. A typical Xilinx IOB has three data paths. On the input path, the logic signal presented at the FPGA pin is routed through an internal buffer that feeds a programmable delay mechanism. The output of the programmable delay block can be routed directly to the FPGA logic or through a latch and then out to the FPGA logic. A simplified block diagram of the FPGA input path is shown in Figure 2.

The second and third data paths work cooperatively to form a programmable output path, which has the ability to be coaxed into high impedance or tri-state mode. Figure 3 gives us an



■ FIGURE 3. This graphic is greatly simplified as you really only need to understand the concept. There are actually two storage blocks available in each output path. In addition, the same pull-up/pull-down and ESD circuitry that is made available to the input path is also available to the output path.

■ PHOTO 1. This is the only Spartan-3A variant that is available in a pinned package. Only 144 pins. We can handle this.



■ PHOTO 2. We can handle this, too. This development board was intended to demonstrate the capabilities of the Spartan-3A FPGA family. We're going to use it as a launch pad into FPGA space.

executive view of the Xilinx programmable output block. The direct output path looks very similar to our LUT output path. The output signal can be driven by a storage block or simply routed directly to the FPGA output pin via the multiplexer and the three-state output driver. The tri-state output path is used to drive the three-state output driver's output into high impedance mode. Note that programmable storage elements are present in both of the output paths. To complete the feature set offered by the Xilinx IOB, every signal path that enters an IOB has an associated programmable inverter option.

There's one more basic thing you need to understand about FPGAs. When the lights go out, so does the FPGA program. Therefore, if we want our LEDs to blink every time we power up our FPGA hardware, we need to include some program storage for the FPGA to boot from. The FPGA program storage can be in the form of serially-interfaced (SPI) or parallel-interfaced memory. We can also get fancy and use a microcontroller to load an FPGA. We'll be using the official Xilinx Platform Cable USB on the FPGA's JTAG interface to download our FPGA designs. Using the FPGA JTAG interface for programming the FPGA also opens up the use of Xilinx's JTAG-accessible Platform Flash as our FPGA boot memory element.

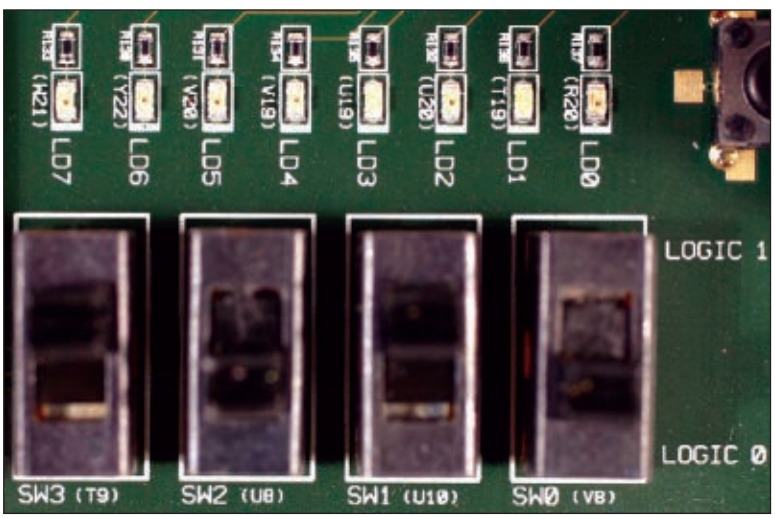
If you had the opportunity to participate in our past Design Cycle CPLD discussions, you'll see that we are using the very same CPLD support equipment (platform cable USB programmer and ISE WebPACK software) to load our design logic into Xilinx FPGAs. The only thing we're going to change is our programming language. Instead of using ABEL, we're going to lay down our FPGA logic with Verilog. Before we start our Verilog coding, let's take a quick look at the hardware target we'll be working with.

THE XILINX SPARTAN-3A FPGA

Our goal is to build up some home-brew FPGA hardware using a Xilinx XC3S50A like the one you see in Photo 1. Since all of the members of the Spartan-3A family of FPGAs have identical basic characteristics, we can do our preliminary FPGA firmware and hardware design work on a prefabricated Spartan-3A-equipped demo board.

The Xilinx Spartan-3A Starter Kit you see in Photo 2 has way more stuff on it than we're going to need right now. However, the simple and necessary things we're going to need here (like LEDs, pushbuttons, RS-232 interface circuitry, and an LCD) are included as subsystems in the kit. All we have to do to use the starter kit's resources is map them into our FPGA application. The mapping is done within ISE WebPACK with the User Constraints Floorplan I/O utility.

As we progress through our FPGA projects, I am going to pull selected items from the Spartan-3A kit and associate them schematically with our Verilog code. If you want to see what the starter kit looks like as a whole from a schematic point of view, you can download the Spartan-3A Starter Kit schematic from the Xilinx



■ PHOTO 3. Although LEDs and switches are easy to manipulate with most any microcontroller, CPLD, or FPGA, we must pay attention to where they are best connected to their hosts. The LEDs are attached to high current FPGA outputs while the slide switches are connected to FPGA dedicated input pins. Note the FPGA pin locations I used to map the LEDs and switches into my Verilog code are silkscreened in parentheses.

website. Let's begin by directing our attention to the bank of LEDs on the starter kit printed circuit board (PCB). We'll write a bit of Verilog code to instruct the FPGA to do something constructive with the LEDs and slide switches I've captured in Photo 3.

TURNING ON THE LIGHTS WITH VERILOG

Most of you already know how to program microcontrollers and personal computers in Basic or C. For you C and Basic programmers, picking up Verilog will be effortless. However, since making assumptions turns me into a donkey, I will approach Verilog as if all of you know little to nothing about C, Basic, or Verilog.

I've pulled the LED and slide switch area from the schematic and transplanted them into Schematic 1. The 700A is packaged in a BGA (ball grid array) package, which explains the alphanumeric FPGA pin identifiers (W21, Y22, etc.). Since we're taking hardware pointers from the Spartan-3A starter kit, I'll point out that all of the LED FPGA I/O pins are located in Bank 1 of the 700A. The reason for this is that Spartan-3A FPGAs allow up to 24 mA of drive current from I/O pins located in Bank 1 and Bank 3.

Banks 0 and 2 are only able to supply a maximum of 16 mA of drive current. The slide switches are also strategically pinned to the 700A. All of the slide switches are pinned to dedicated FPGA input pins located in Bank 2. From the perspective of our targeted 50A, here's how the FPGA bank pins fall out:

Bank 0 = pins 109 – 144
Bank 1 = pins 73 – 108
Bank 2 = pins 37 – 72
Bank 3 = pins 1 – 36

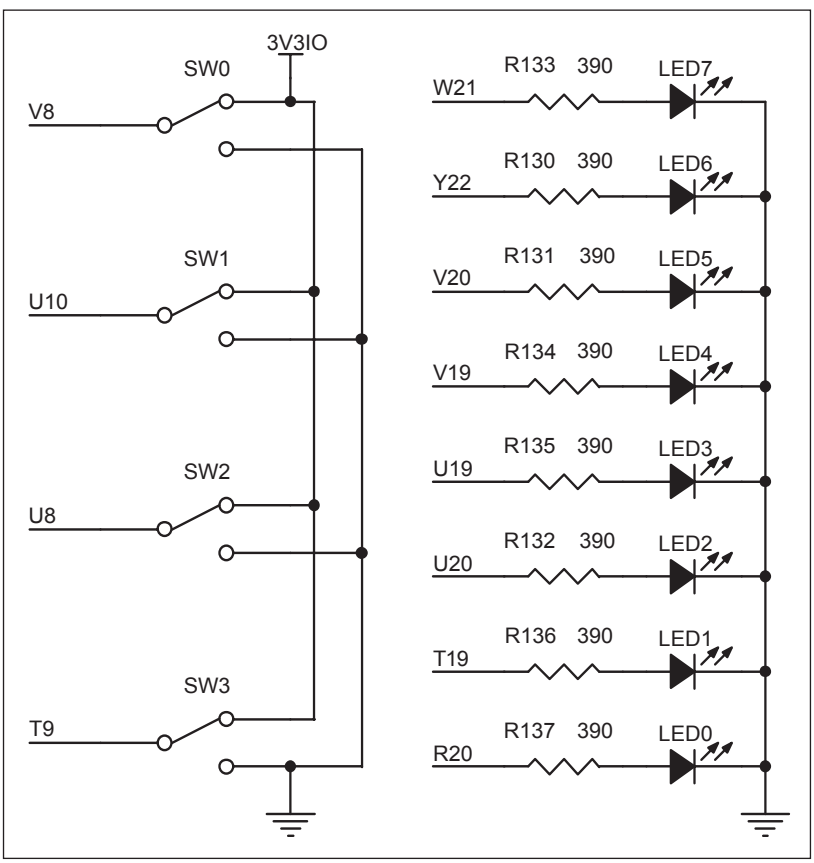
That works out to a bank being a complete side of the square FPGA package you see in Photo 1. If you orient pin 1 of the 50A in the upper left corner (looking down onto the legend side of the FPGA IC), Bank 0 consists of the pins along the top pin row of the FPGA. The successive FPGA banks flow in a clockwise direction with Bank 1 being made up of the right-hand pin column of the 50A. Bank 2 runs along the bottom row of the FPGA and Bank 3 is positioned in the left-hand column of pins opposite to Bank 1. Believe it or not, the same banking scheme is applied to the 700A BGA package with ball A1 oriented in the upper left corner and ball AB22 in the bottom right corner.

One must understand the basic I/O principles of a microcontroller before being able to code more complex I/O-oriented tasks. The same holds true for FPGAs. So, let's write some Verilog code that will mirror the slide switch positions in the LED bank. A slide switch is in the "ON" position when the slide switch common terminal presents a logical high to the FPGA. Conversely, the slide switch "OFF" state is represented by a logical low at the FPGA input pin. We'll illuminate the corresponding LED when a slide switch is "ON."

Verilog is based on modules. Verilog modules use ports as I/O mechanisms. The arguments associated with a module are contained in the port list, which follows the name of the module in the module declaration. Consider this Verilog code snippet:

```
module slide_to_led(
     input sw0_in,
     input sw1_in,
     input sw2_in,
     input sw3_in,
     output led0_out,
     output led1_out,
     output led2_out,
     output led3_out
     );
endmodule
```

Our first Verilog module is called slide_to_led. The module ports (arguments) consist of our slide switch inputs and four of the LEDs which are defined as outputs. Note the use of commas, parentheses, and a semicolon to bracket the port list. That looks a



■ SCHEMATIC 1. Since the Spartan-3A starter kit designers have already assigned FPGA pins to these components, we must use the ISE WebPACK Floorplan I/O utility to map these into our FPGA application. Note that the FPGA pin designations here match those found in Photo 3.

lot like C to me. As we add more Verilog source, you'll notice the minimal use of braces ({}). Verilog likes to replace braces we use so often in C with begin and end statements. Braces do have a place in the Verilog scheme of things as Verilog employs braces to concatenate and replicate.

Our slide_to_led code won't do much in its current state. Since we want to control the LEDs with the slide switches, the most logical Verilog code would look like this:

```
module slide_to_led(
     input sw0_in,
     input sw1_in,
     input sw2_in,
     input sw3_in,
     output led0_out,
     output led1_out,
     output led2_out,
     output led3_out
     );

always @(sw0_in,sw1_in,sw2_in,sw3_in)
 begin
if(sw0_in)
     led0_out = 1;
else
     led0_out = 0;

// if/else code for rest of switches goes here
 end
endmodule
```

Naturally, we would include the appropriate if/else statements to cover all of the rest of the LEDs and slide switches. The Verilog if/else statements are just like their C counterparts with the exception of the C braces, which are replaced by Verilog begin and end operators when the need arises. The good old do/while(1) loop-forever C code has been replaced here by the Verilog always @ loop code. Everything between begin and end inside of the always loop is executed every time one of the slide switch logic levels is changed. In other words, a Verilog always loop runs freely and triggers on the arguments in the sensitivity list. In our case, the logic levels of the slide switches make up our always @ sensitivity list. There are times when you can run a Verilog always loop without a sensitivity list. Doing a plain vanilla always loop is just like running a never-ending while(1) C loop.

After all of that typing, we would find that this code doesn't work. The key to writing some working code lies behind understanding what Verilog is doing to us here. Here's what the code really looks like under the Verilog covers:

```
module slide_to_led(
     input wire sw0_in,
     input wire sw1_in,
     input wire sw2_in,
     input wire sw3_in,
     output wire led0_out,
     output wire led1_out,
     output wire led2_out,
     output wire led3_out
 );

always @(sw0_in,sw1_in,sw2_in,sw3_in)
 begin
  if(sw0_in)
     led0_out = 1;
 else
     led0_out = 0;

// if/else code for rest of switches goes here
 end
endmodule
```

Verilog uses the data type wire to connect modules and gates. Think of a Verilog wire just as you would a piece of wire in one of your electronic projects. I added the Verilog wire data type into our Verilog module manually for illustrative purposes as Verilog defaults all of the module arguments to the data type of wire. Verilog wires can only be read/driven by a continuous assignment statement or tied to an input or output of a module or gate. Thus, we can't write a logical "1" or logical "0" directly to led0_out as we attempted to do in our Verilog module code because led0_out is a Verilog wire.

The fix for our faulty Verilog module is simple:

```
module slide_to_led(
     input wire sw0_in,
     input wire sw1_in,
     input wire sw2_in,
     input wire sw3_in,
     output reg led0_out,
     output reg led1_out,
     output reg led2_out,
     output reg led3_out
     );

always @(sw0_in,sw1_in,sw2_in,sw3_in)
 begin
  if(sw0_in)
     led0_out = 1;
 else
     led0_out = 0;

// if/else code for rest of switches goes here
 end
endmodule
```

The Verilog data type reg is short for register. Verilog registers are able to hold their values from procedure to procedure. We can also read them and write them. Don't get too cozy with the concept of a Verilog register being a piece of silicon as reg is a Verilog data type just like a Verilog wire. All we really care about is how, when, and where to use regs and wires best.

Now would be a good time to show you how continuous assignment works. Let's use our original default-to-wire module code and add some Verilog assignment code to handle getting the slide switch states out to the LEDs:

SOURCES

Xilinx — **www.xilinx.com**
XC3S50A; XC3S700A; ISE WebPACK;
Spartan-3A Starter Kit; Platform Cable USB

Saelig — **www.saelig.com**
CleverScope

```
module slide_to_led(
    input sw0_in,
    input sw1_in,
    input sw2_in,
    input sw3_in,
    output led0_out,
    output led1_out,
    output led2_out,
    output led3_out
    );

    reg led0;
    reg led1;
    reg led2;
    reg led3;

    assign led0_out = led0;
    assign led1_out = led1;
    assign led2_out = led2;
    assign led3_out = led3;

    always @(sw0_in,sw1_in,sw2_in,sw3_in)
    begin
        if(sw0_in)
            led0 = 1;
        else
            led0 = 0;
        if(sw1_in)
            led1 = 1;
        else
            led1 = 0;
        if(sw2_in)
            led2 = 1;
        else
            led2 = 0;
        if(sw3_in)
            led3 = 1;
        else
            ed3 = 0;

    end
endmodule
```

Note that I removed all of the explicit data type definitions. Doing that allows all of our port arguments (inputs and outputs) to default to wire. We have already proven that we can't directly drive a Verilog wire with code alone. So, we have to add something to our Verilog code to drive the ledx_out wires. That "something" is a quartet of Verilog registers: led0, led1, led2, and led3. To have the newly added Verilog regs drive the Verilog LED output wires, we assign each of the ledx registers to its logically associated ledx_out wire. The rest of the if/else Verilog code remains the same, sorta. Note that now we must write to our newly added ledx registers as our ledx_out entries are now Verilog wires.

FPGAs are natural born counters. Now that we have a grasp on FPGA I/O operations, let's build on our Verilog knowledge and code up an eight-bit counter that reveals itself via the LEDs.

BLINKING THE LIGHTS WITH VERILOG

The Spartan-3A starter kit is equipped with an on-board 50 MHz oscillator. There's no way we humans can see a 50 MHz scan rate in the LED bank. So, we must divide the incoming 50 MHz clock to produce a scan rate that we can see in the LED bank. To keep things simple, we'll craft our clock divider to run on powers of 2.

Let's shoot for a scan rate of around 10 Hz. That means that we must divide our 50 MHz clock by 5,000,000. The divisor value in hexadecimal is 0x4C4B40. The idea is to key our clock divider on an overflow of the most significant bit. We can't do that accurately with 0x4C4B40. So, let's use 0x3FFFFF as our clock divisor. We'll count from 0 to 0x3FFFFF and reset our divisor when it rolls over to 0x400000. Let's do the math to see what scan rate that will give us:

Scan rate = 50,000,000 Hz / 0x3FFFFF
(4,194,303 decimal) = 11.92 Hz

To double-check our scan rate math, let's compute the period of 11.92 Hz and take a snapshot of the scan rate with a CleverScope:

Period of 11.92 Hz = 1 / 11.92 = 0.084 seconds or 84 ms

Screenshot 1 confirms our scan rate. Here's the Verilog code that produced the waveform you see in Screenshot 1:

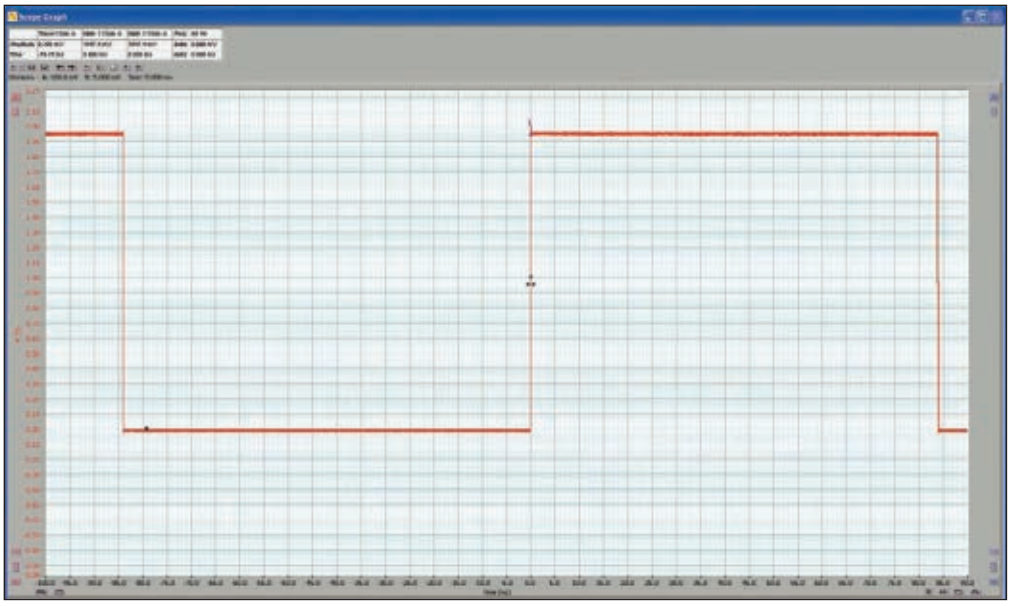
```
module led_cntr_code(
    input clk,
    output reg [7:0] led_out
    );

reg [22:0] clk_divider;

always @(posedge clk)
begin
    clk_divider <= clk_divider + 1;
    if(clk_divider[22])
    begin
        clk_divider[22] <= 0;
        led_out <= led_out + 1;
    end
end
endmodule
```

There's some new stuff in the LED counter code. However, I don't think you'll have any problems figuring out what our Verilog code is doing. Our 50 MHz clock is fed into the FPGA via the clk input, which is assigned to an FPGA clock input pin (E12). The LED output is defined as an eight-bit (bits 7 through 0) register with each of its led_out LEDs tied to an FPGA output pin as specified in Schematic 1. Our 23-bit clock divider register collects the 50 MHz ticks and is reset every time the most significant bit (bit 23) is equal to 1. At every clock divider reset, the led_out register is incremented and the LEDs reflect the value of the led_out register.

Note that our "always" sensitivity list is focused on the rising edge of every clock cycle of the incoming 50 MHz clock. Thus, this always loop's contents are executed on



■ SCREENSHOT 1. I captured this waveform on the LED0 anode. As you can see, our scan rate math is confirmed on both sides of the center of the waveform.

every rising edge of the 50 MHz clock. Note also that the "=" operator we used in our slide switch code has been replaced with "<=" in our counter code. The "=" operator is called a procedural blocking assignment, which means that statements that use it will execute in the order of their appearance. When blocking is employed, the next statement will not execute until the current statement execution has completed. The "<=" operator is non-blocking. All non-blocking statements execute in parallel. As the non-blocking operator infers, the non-blocking statements are evaluated right to left. Non-blocking operation closely models a physical flip-flop and should be used in clocked always loops. Blocking statements are best suited for combinatorial logic like our slide switch code.

DUST OFF YOUR SOLDERING IRON

... because next time we're going to build up our own homebrewed XC3S50A FPGA hardware.

All of the Verilog code in this installment of Design Cycle was written using Xilinx ISE WebPACK version 10.1.01, which is a free download from the Xilinx website. I've stuffed all of the projects into a download package on the *Nuts & Volts* website (**www.nutsvolts.com**) so you can run the FPGA projects just as we ran them here. You don't need any FPGA hardware to compile the project code.

I've included the entire project file set for both projects so that you can look at all of the ISE WebPACK options and settings. For instance, if you're wondering how I assigned FPGA pins to the LEDs and slide switches, you can see how I did it by looking at the User Constraints Floorplan I/O utility entries, which are available from the ISE WebPACK Processes window.

With our FPGA projects verified on the Spartan-3A starter kit, we now have some known-good test code we can run on the XC3S50A hardware we'll build up in the next edition of Design Cycle. **NV**

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■ *Fred Eady can be contacted via email at fred@edtp.com.*

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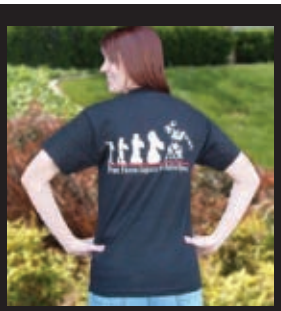
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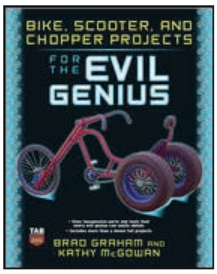

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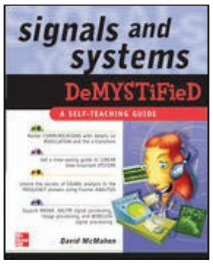

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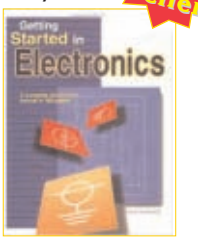

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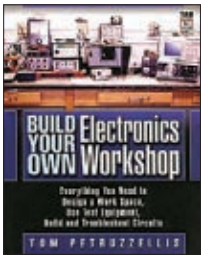

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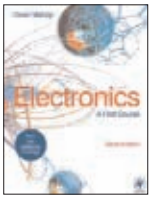

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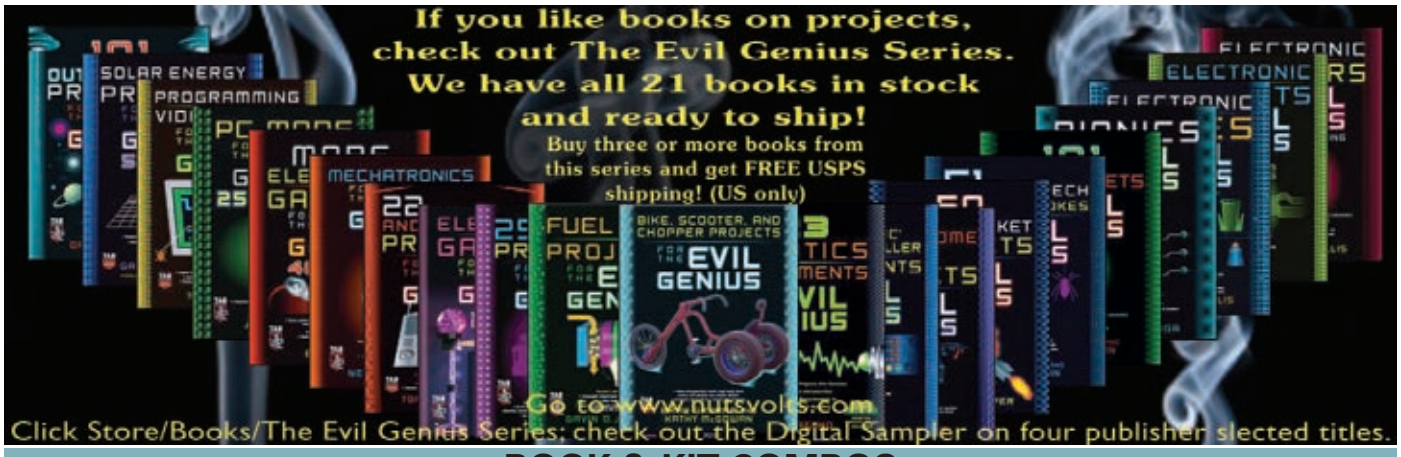

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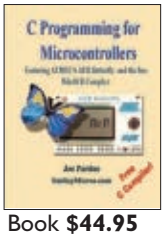

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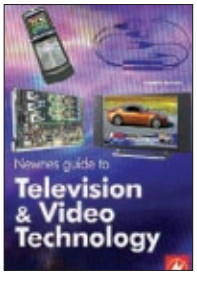

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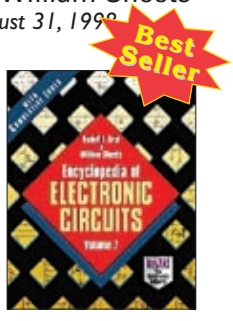
by Rudolf F. Graf / William Sheets
Publish Date: August 31, 199?



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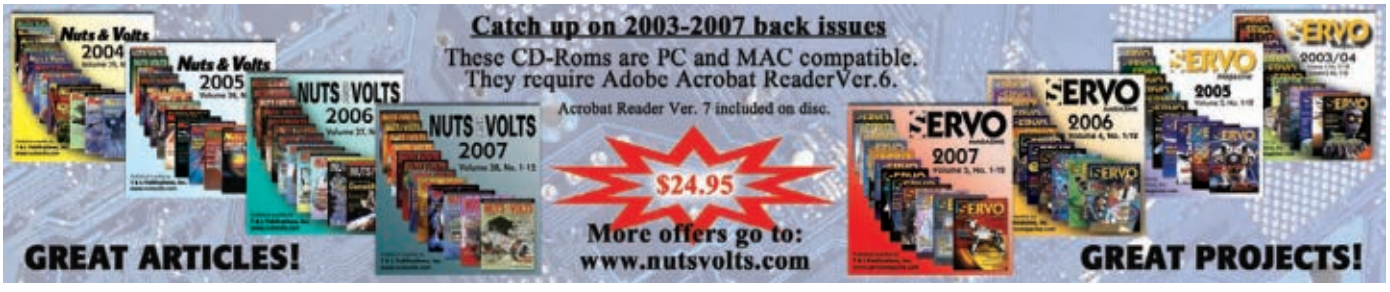

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PROJECTS

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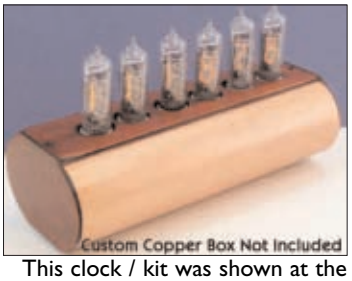

As seen on the October 2006 cover

Nixie tube clocks fuse the spirit, drama, and eerie beauty of cold war technology with modern inner works to create uncommon handcrafted timepieces. This clock / kit was shown at the May 2008 MAKER Faire in San Mateo, CA by *Nuts & Volts Magazine* and was very well received as a novel way to show the Nixie tubes. Plus, it's a great kit for all levels of electronic experience.

For more information, please check out your October 2006 issue or go to our website @ www.nutsvolts.com

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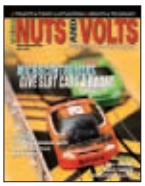
As seen in the May 2008 issue



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As seen on the February 2008 cover

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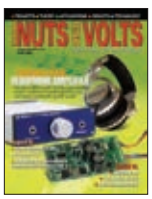

Need to regulate your power output? Take a look at this new and improved regulator. **For more information, please check out your June 2008 issue or go to our webstore @ www.nutsvolts.com**

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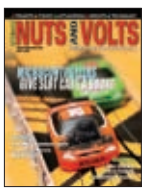

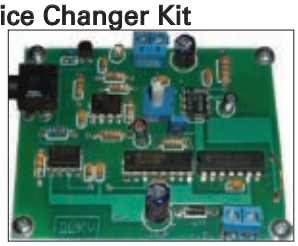

Have fun with the whole family with this project. Put your newly ***changed*** robotic ***voice*** on your outgoing phone message, or use it on those annoying telemarketers!

For more information, please check out your May 2008 issue

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$ 20.95*

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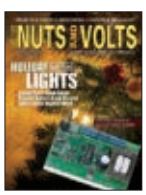


As seen in the November 2007 issue

Have you ever laid in bed and wondered ... is the garage door open? Get more info @ www.nutsvolts.com

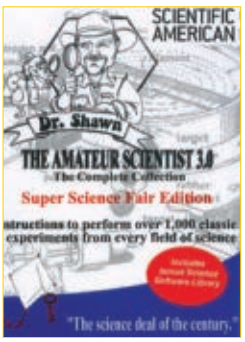
Subscriber's Price **$49.95**

Non-Subscriber's Price **$57.45**

Kit includes article reprint, complete instructions, parts list, and hole drilling templates.

The Amateur Scientist 3.0 The Complete Collection

by Bright Science, LLC



There are 1,000 projects on this **CD**, not to mention the additional technical info and bonus features. It doesn't matter if you're a complete novice looking to do their first science fair project or a super tech-head gadget freak; there are enough projects on the single CD-ROM to keep you and 50 of your friends busy for a lifetime! **$26.99**

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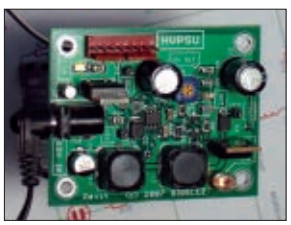

As seen on the April 2008 cover

It's fun to collect and experiment with forgotten technology! But, you'll need a stable high voltage power supply to get started.

For more info, go to the *Nuts & Volts* Webstore **www.nutsvolts.com**

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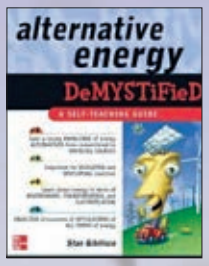
ALTERNATIVE ENERGY SECTION

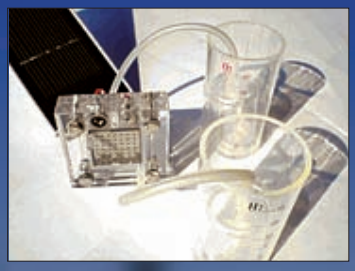
Alternative Energy Demystified
by Stan Gibilisco

Publish Date: October 23, 2006



The fast and easy way to get up-to-speed on alternative energy. Because of current events, geopolitics, and natural disasters, the cost of fuel is front and center in our lives. This book provides a concise look at all forms of energy, including fossil fuels, electric, solar, biodiesel, nuclear, hydroelectric, wind, and renewable fuel cells. You will get explanations, definitions, and analysis of each alternative energy source from a technological point-of-view. **$19.95**

Solar Hydrogen Power Generation Set



The Solar Hydrogen Generation Set includes a solar cell, a PEM reversible fuel cell, as well as oxygen and hydrogen gas containers. The set only needs pure water to create hydrogen and produce electricity. Perfect for science labs, classroom use, or demonstration purposes.
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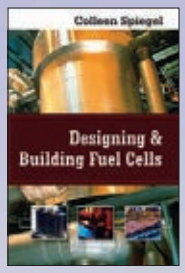
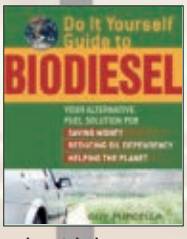
Designing & Building Fuel Cells
by Colleen Spiegel



Designing & Building Fuel Cells equips you with a hands-on guide for the design, modeling, and construction of fuel cells that perform as well or better than some of the best fuel cells on the market today. Filled with over 120 illustrations and schematics of fuel cells and components, this "one-stop" guide covers fuel cell applications, fuels and the hydrogen economy, fuel cell chemistry, thermodynamics and electrochemistry, fuel cell modeling, materials, and system design, fuel types, delivery, processing, and much more. **$89.95***

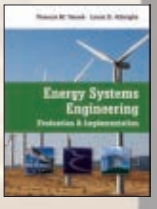
Do It Yourself Guide to Biodiesel
by Guy Purcella



Contains the most current and complete information available for would-be biodiesel makers. This book offers a step-by-step path from the initial desire to do something good for the environment to the final stage of filling the tank with low-cost fuel. Readers are given a complete understanding of what biodiesel is and how to make it properly and safely. There is even a section on pitfalls to avoid, as well as the author's personal tips and tricks. **$15.95**

Energy Systems Engineering
by Francis Vanek, Louis D. Albright

Publish Date: June 13, 2008



A unique systems approach to energy engineering, covering carbon-based, nuclear, and renewable sources! Filled with over 200 detailed illustrations and tables, the book examines short-, medium-, and long-term energy options for the remainder of the twenty-first century. For each energy system, the authors provide equations and problems to help practitioners quantify the performance of the technology and better understand its potential. **$89.95***

The Complete Idiot's Guide to Solar Power for Your Home
by Dan Ramsey / David Hughes

Publish Date: May 2007

The perfect source for solar power — fully illustrated. This book helps readers understand the basics of solar power and other renewable energy sources, explore whether solar power makes sense for them, what their options are, and what's involved with installing various on- and off-grid systems. **$19.95**

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READER FEEDBACK

continued from page 10

less bandwidth, don't send all the sync info. H/V sync in the analog signal takes up about 20% of the bandwidth. In the digital world, all that can take up one byte. Saved a bunch of space there!!! Do some creative compression, data processing, error correction, remove parts of the image people won't notice, and before you know it you have squeezed that digital signal into less space than the analog one.

I get tired of everyone saying that the digital signal is better — it's not all the time. I would tell people if they thought that, then they had not seen a really good analog signal! If you take a good look at a digital TV picture, you will see lots of picture faults. Most people don't notice these faults and the broadcast companies can get away with it. If, in the past, a broadcast company broadcast a picture with as many impairments as in the digital picture, their phones would be ringing off the hook. Thank you for your time.

Donovan Stenger
Broadcast Technologist

TRYING TO TUNE IN

Apparently I always have things backwards! If the advertisers are to be believed, the whole world wants to watch video on their iPod, iPhone, or laptop. Apple even comes out with iTV figuring people's monitors to be smaller than the wide screen TVs they are sure to own. Not me!

I have an Apple 30" Cinema Display connected to a 2 GHz dual G5 running Mac OSX 10.4.x Thanks to iDVD, I can watch DVDs on this, but the problem came with trying to watch cable TV.

When I upgraded from analog to digital cable service from Time/Warner, I insisted on a set top box E/W a Firewire® output. After connecting everything together, the G5 reports seeing the Scientific Atlanta "Explorer" 3250HD STB at the Firewire input, but refuses to T anything with it.

In the interim, I have opted to use a MIGLIA TVMini HD (now discontinued) digital over-the-air tuner. The FCC in its infinite wisdom has edicted (if the news readers on TV can make "impact" a verb, why not "edict"?) all broadcast TV stations to have digital over-the-air programing. These are on other frequencies from their VHF/UHF programing. The MIGLIA tuner outputs on USB 2.0 and came with a driver package called eyeTV2. Unfortunately, the password issued for the tuner restricts the driver to only access the USB port, even though there are other drivers provided which may have made the Firewire port available for input, and thus the STB viewable.

There are channels from my STB that I cannot get from local broadcasters that I wish to view with my setup. I can only assume that the STB must utilize a standard protocol if it is to be compatible with any TV set that has a Firewire input. There are discussions on line about recording from STBs, my only interest is to view. Please, do you have any advice?

Thanks in advance for your most kind consideration.

Tall Henning

Response: You have quite a nice setup there. While Firewire has been around for a while, it's not in common use to connect home theater equipment. The Scientific Atlanta "Explorer" 3250HD you have specifies the Firewire connectors as "reserved for future use." Depending upon which of the two main software OS your box is running, these connectors may someday be active. Until then, I think you will have to find another way to hook up your STB.

I assume you are using your Mac as the hub, probably hoping to let it perform DVR functions. If not, I would suggest replacing the STB with a unit that has DVI or HDMI output. You could use a DVI switch (perhaps w/remote control) to toggle between the computer and STB. And you could have a DVR in the STB as well (for a fee, of course).

Probably not what you wanted to hear, but unless you want to go shopping for a new STB (cable companies are now required by law to let you buy your own), there's nothing else you can do.

Jeff Mazur
Author of previous NV HDTV articles

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TECH FORUM

This is a READER-TO-READER Column.

All questions *AND* answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and NO GUARANTEES WHATSOEVER are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

All questions and answers should be sent by email to forum@nutsvolts.com All *diagrams should be computer generated and sent with your submission as an attachment.*

QUESTIONS

To be considered, all questions should relate to one or more of the following:

❶ Circuit Design
❷ Electronic Theory
❸ Problem Solving
❹ Other Similar Topics

■ Be brief but include all pertinent information. If no one knows what you're asking, you won't get any response (and we probably won't print it either).
■ Include your Name, Address, Phone Number, and email. Only your Name, City, and State will be published with the question, but we may need to contact you.
■ No questions will be accepted that offer equipment for sale or equipment wanted to buy.
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■ Include in the subject line of your email, the question number that appears directly below the question you are responding to.
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■ Only your Name, City, and State, will be printed, unless you say otherwise. If you want your email address included, indicate to that effect.
■ Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

>>> QUESTIONS

I'm looking for information on power line communication systems. Does the US power grid broadcast any information that can be read from the power lines coming into my home? Are there any projects that can tap that information?

#8081 **Steven Van Epps**
via email

I need info on refurbishing or building custom solar yard lights. I currently have a Lighthouse lawn ornament that has a solar light that doesn't recharge the replaceable rechargeable battery. Information on troubleshooting would be helpful for what I assume to be a fairly common circut. I would also like to illuminate the lantern of a Lawn Jockey and a Pagoda. Adding multiple LEDs with changing colors and blinking patterns could also be a take off. Anyone have a circuit?

#8082 **Mike Hoffert**
via email

>>> ANSWERS

[#5084 - May 2008]

I'm looking for an affordable (US) PCB MFG who specializes in prototype quantities (<100) of COB (chip on board) from DIE that I provide. I need a company who can lead-attach the DIE and epoxy-seal it, forming a COB PCB.

#1 I found these companies online. They offer prototype services among others.

IDAX microelectronics Lab
Anaheim, CA
714-632-5088
www.idaxlabs.com/services.asp

Quik-Pak
San Diego, CA
858-674-4676
www.icproto.com/products/

Majelac Technologies
Aston, PA
610-459-8786
www.majelac.com/

Daryl
via internet

#2 I have had prototype and full production PCBs made with the company listed below, with excellent personal service, board quality, and pricing without any problems for over 25 years. They are directly associated with several companies that will provide your requests with great satisfaction.

Northern Circuits, Inc.
East Syracuse, NY
315-463-8531, 800-378-0490
http://northerncircuits.com/

John F. Mastromoro
Saint Johnsville, NY

#3 Hybrid Design Associates **www.hda-smc.com/** in Tempe, AZ may be

able to help you. They are not inexpensive, but they are capable of doing almost any COB assembly.

Robert Zusman
Scottsdale, AZ

[#6081 - May 2008]

Has anyone adapted surplus computer parts for other uses? For example: adapting on old sound card for use as an amplifier. If so, please tell what you did and how. Also, can someone explain the similarities and differences between audio CDs and DVDs?

#1 The power supply in the PC can be used, with just a small modification. There are a number of write-ups telling you how on the web — here's one: **http://web2.murraystate.edu/andy.batts/ps/powersupply.htm**

You can find many uses for parts scrounged from old PCs.

Figure 1 is a zener tester circuit built exclusively from parts out of a defective CRT monitor. Attach a volt meter and the zener to be tested across the DUT terminals. The meter measures the zener voltage on zeners up to about 100 volts. The oscillator and transformer produce the high (about 100) voltage; the Q2-Q3 circuit limits the current to about 12 mA. The part numbers available from a different CRT monitor may not be the same — but all of them have high voltage transistors (needed for Q2 and Q3) and a suitable transformer. Power dissipation in Q2 can run over a watt, so you want to select Q2 from those available in the monitor for maximum power dissipation. You can also reduce the input voltage to lower the high voltage level and power dissipation, with a resistor in series or a lower voltage supply. The high voltage level depends on T1 — a different T1 would yield a different high voltage level. You can measure the high voltage level at the device under test (DUT) terminals with nothing other than the meter connected there. Tests should be brief, in any event, as the meter displays the zener voltage immediately.

Ed Schick
Harrison, NY

#2 While many good quality and interesting function PC parts can be recycled, it's quite hard to make the surplus boards play outside of the PC environment. This is because most — if not all — PC peripherals require programming at start-up. Even simple devices such as audio cards require configuration from the PC's operating system (the "driver files" loaded to the OS when the cards are first installed). In operation, digital commands to configure the audio paths and signal levels are established every time the PC boots. It's better to view these surplus cards as a source for components, and/or as practice for soldering rather than for adaptation to other projects.

All compact discs (CDs) operate on the same principle that was invented by Philips and Sony in 1980 and presented as the "Red Book" Standard. It was designed for high quality audio, using digital encoding and various error correcting schemes to overcome fingerprints or blemishes on the disks. The disks were mass produced by stamping and are read only, in a 120 mm diameter x 1.2 mm thick format. The data begins on the inner tracks and spirals outward, allowing smaller disks (80 mm Mini-CD) and novelty shaped disks to be used. The read laser operates at 780 nm (infrared).

Later, the same 120 mm disks were adapted for computer data storage, under the "Yellow Book" Standard for CD-ROMs. The "Orange Book" Standard further defined a WORM (Write Once Read Many) disk that can be recorded by an end user drive — called CD-R — and a fully read-erase-write disk called CD-RW, by "burning" the inner disk surface with a higher power laser.

Various speed enhancements have been made; the 1X disk spins at approximately 200-500 RPM, and records in real time (80 mins audio or 700 MB data for a complete disk), currently 52X drives record the same 700 MB of data in about 90 seconds!

For full length movies, a higher density 120 mm disk called DVD (Digital Versatile Disk) was added in 1997, with six times the data density but the same physical size as the CD. The DVD uses a 650 nm (visible red, same as a laser pointer) reading laser, and is also available as a WORM disk and erasable disk media. There are three standards in common use causing confusion. The "plus" standard (DVD+R) can only be recorded once, unlike the "minus" standard (DVD-R, DVD-RW) and DVD-RAM standard. DVD-RAM is popular with camcorders and personal video recorders since 1998, and stores data in concentric tracks (like a hard drive or floppy) while CD, DVD+R, and DVD-R use a spiral track.

The DVD disks can have data on both sides, and are further enhanced by "dual-layer" technology that allows data to be stored on a second internal layer.

The latest addition to optical media is the Blu-Ray disk which uses a 405 nm wavelength laser — allowing a six fold increase in data storage compared to DVD. Blu-Ray (BR) technology became the winner of the recent high definition disk format wars

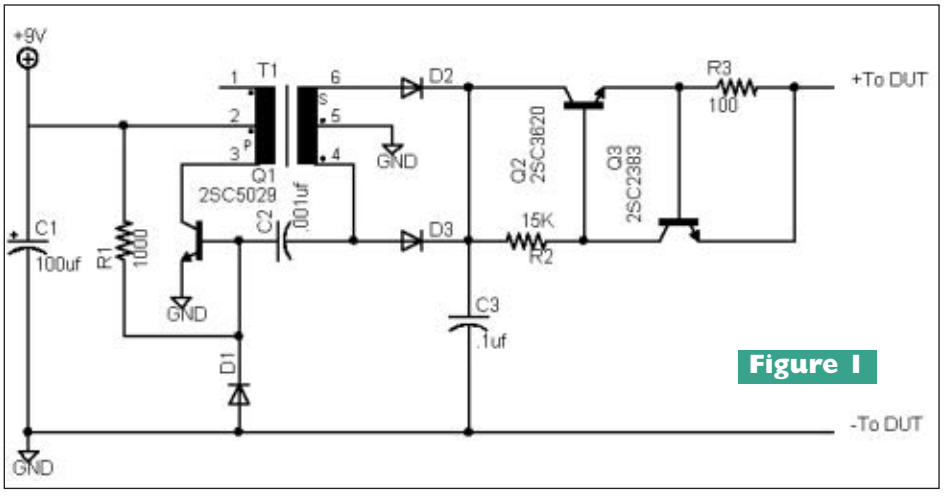

Figure 1

when Toshiba abandoned the competing DVD HD format is February 2008.

Peter Stonard
Campbell, CA

[#6083 - May 2008]

How can I configure a small LCD display as a voltmeter and/or amp meter?

#1 The raw LCD component is a glass screen with the LCD liquid sandwiched inside and transparent terminals that usually connect to a socket, ribbon cable, or other PCB-friendly contacts, such as this one **http://tinyurl.com/4hxuv6** An LCD module is similar but has the driver electronics embedded on the glass. The raw display needs the electronics to be added, and both voltage levels and timing are critical to operate the LCD — so an LCD module with interface electronics is preferred.

Starting with an LCD module, such as **http://tinyurl.com/4enbco** would still require additional circuits to scale the analog input voltage, rectify it for AC ranges, and convert it to a digital data stream that is decoded to drive the LCD display. There are custom and Application Specific Integrated Circuits (ASIC) to do this, and these are built into commercial LCD voltmeter modules — which can be had for little money on auction sites.

To build an LCD voltmeter from scratch would be uneconomical but fun for a hobbyist. A good place to start is with an Application Specific Standard Product (ASSP) like **http://tinyurl.com/4rbvjs**. Another approach would involve a uC (microcontroller) — many of which have ADC converters and I/O for driving an LCD module on a single chip.

Peter Stonard
Campbell, CA

#2 There are basically two ways this can be done, depending upon the type of LCD display you want to use. The easiest way is to use a digital panel meter (available from quite a few *N&V* advertisers), LCD, or LED, with a voltage divider for the voltmeter application or a shunt for the ammeter. (Figure 2) The other way is to use a microcontroller with an A/D converter driving a HD44780-based LCD panel. There are several books which cover this subject quite well: *Programming the PIC Microcontroller with MBasic* by Jack Smith is an excellent starting point using Basic as the programming language and *Advanced PIC Microcontroller Projects in C* by Dogan Ibrahim if you want to use C. *PIC in Practice* by D.W. Smith covers this subject in assembler. Keep in mind that the A/D converter will give you a 10-bit word for most PIC microcontrollers and needs to be converted, which is tedious to write in assembler, but is the fastest alternative. There are other ways, such as using I^2C or SPI A/D converters (Microchip Technology's MCP3421 18-bit I^2C A/D or their 22-bit converter).

Walter Heissenberger
Hancock, NH

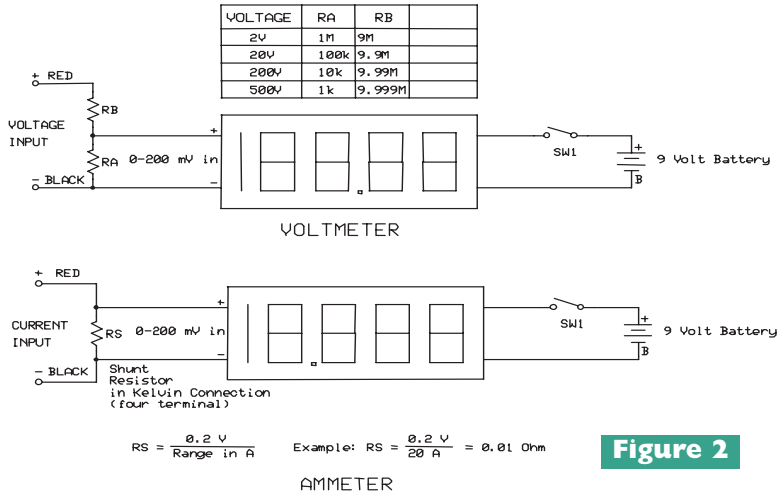

Figure 2

[#7083 - July 2008]

How can I interface data collecting hardware (data loggers and real-time hardware) with Microsoft Excel through serial or USB ports?

#1 There are two parts to solving this job. Communication between the PC and data loggers, and converting the data to a format that MS Excel understands. If the data loggers/real time hardware store the data, then send it on command; a serial terminal program (like Hyperterminal) with "capture to file" turned on may be used to collect the data. On the other hand, if the data loggers send the data as it happens, then a specialized communication program is needed. This is because Hyperterminal isn't designed to have capture to file left on for long periods. For a format that MS Excel understands, I suggest CSV (Comma Separated Values) files. This would be done with a program or script that parses the raw data and creates the CSV file. A USB-to-serial converter looks like a serial port, allowing terminal programs to work over USB connections. A data logger that has a USB port — instead of a serial port — should come with an interface program for the PC.

Dale Yarker
via email

#2 There are several low cost Shareware utilities that can read data from your COM port and populate a MS Excel spreadsheet, for example: COMxL RS232C from Lye-tech, **http://tinyurl.com/4ac7xr**

Peter Stonard
Campbell, CA

#3 I am assuming that you already have the serial signal, therefore you need a software fix. Windmill Software Ltd. has a free RS-232 instrument driver with their Windmill 4.3 software suite. For the free data acquisition software, go to **www.windmill.co.uk/jsarrdms.htm**. They also have a newsletter that is worth subscribing to.

Steve Lueck
Bisbee, AZ

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Cunard Associates 36

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Earth Computer Technologies 36
Jaycar Electronics 11
WeirdStuff Warehouse 36

CCD CAMERAS/ VIDEO

Circuit Specialists, Inc. 99
LITEXPO 36
Ramsey Electronics, Inc. 22-23

CIRCUIT BOARDS

AP Circuits 51
Comfile Technology 98
Cunard Associates 36
Dimension Engineering 9
ExpressPCB 21
FlyPCB 37
LEDkit.biz 37
PCB Pool 78
Pulsar, Inc. 36
SolderByNumbers.com 37, 93

COMPONENTS

Cam Expert, LLC 36
Front Panel Express LLC 74
Jameco 55
Lemos International Co., Inc. 9
Linx Technologies 24
Mouser Electronics 15
Pulsar, Inc. 36
Super Bright LEDs 32

COMPUTER

Hardware

ActiveWire, Inc. 37
Earth Computer Technologies 36
WeirdStuff Warehouse 36

Microcontrollers / I/O Boards

Abacom Technologies 51
Bitscope / Metachip 4
Comfile Technology 98
FlyPCB 37
HobbyLab 36
Microchip 33
microEngineering Labs 85
Mouser Electronics 15
Net Media 2
Parallax, Inc. .....Back Cover
Pololu Robotics & Electronics 74
Scott Edwards Electronics, Inc. 24
Solarbotics/HVW 65
Trace Systems, Inc. 78
XGameStation 37

DESIGN/ ENGINEERING/ REPAIR SERVICES

Cam Expert, LLC 36
Electronic Design Mexico 37
ExpressPCB 21
FlyPCB 37
Front Panel Express LLC 74
PCB Pool 78
Pulsar, Inc. 36
Trace Systems, Inc. 78

DISPLAY

Comfile Technology 98

EDUCATION

Bitscope / Metachip 4
Command Productions 35
LEDkit.biz 37
PAiA 74
SolderByNumbers.com 37, 93
XGameStation 37

EMBEDDED TOOLS

Mouser Electronics 15
NetBurner 5

ENCLOSURES

Integrated Ideas & Tech. 8

EVENTS

Robo Development 75

KEYBOARD EMULATORS

Hagstrom Electronics 36

KITS & PLANS

DesignNotes.com, Inc. 92
Earth Computer Technologies 36
Electronics 123 36
Information Unlimited 60
Jaycar Electronics 11
LEDkit.biz 37
NetBurner 5
PAiA 74
QKITS 37
Rabbit, A Digi International Brand 3
Ramsey Electronics, Inc. 22-23
Scott Edwards Electronics, Inc. 24
Solarbotics/HVW 65
XGameStation 37

LASERS

Information Unlimited 60

LSI (micon)

Renesas Technology Corp 25

MISC./SURPLUS

All Electronics Corp. 67
Front Panel Express LLC 74
WeirdStuff Warehouse 36

MOTORS

Jameco 55

PLASTIC PARTS

Electronic Design Mexico 37

PROGRAMMERS

Electronic Design Mexico 37
Electronics 123 36
microEngineering Labs 85

RF TRANSMITTERS/ RECEIVERS

Abacom Technologies 51
Linx Technologies 24
LITEXPO 36

ROBOTICS

HobbyLab 36
Jameco 55
Lemos International Co., Inc. 9
Lynxmotion, Inc. 24
Net Media 2
Pololu Robotics & Electronics 74
Robo Development 75
Robot Power 73
Solarbotics/HVW 65

SATELLITE

Lemos International Co., Inc. 9

SECURITY

Information Unlimited 60
Linx Technologies 24
LITEXPO 36

TEST EQUIPMENT

Bitscope / Metachip 4
Circuit Specialists, Inc. 99
DesignNotes.com, Inc. 92
Dimension Engineering 9
Electronic Design Specialists 65
HobbyLab 36
Jaycar Electronics 11
Saleae LLC. 37
Trace Systems, Inc. 78

TOOLS

NetBurner 5
Saleae LLC. 37

WIRE, CABLE AND CONNECTORS

DesignNotes.com, Inc. 92
Jameco 55

Abacom Technologies 51
ActiveWire, Inc. 37
All Electronics Corp. 67
AP Circuits 51
Bitscope / Metachip 4
Cam Expert, LLC 36
Circuit Specialists, Inc. 99
Comfile Technology 98
Command Productions 35
Cunard Associates 36
DesignNotes.com, Inc. 92
Dimension Engineering 9
Earth Computer Technologies 36
Electronic Design Mexico 37
Electronic Design Specialists 65
Electronics 123 36
ExpressPCB 21
FlyPCB 37
Front Panel Express LLC 74
Hagstrom Electronics 36
HobbyLab 36
Information Unlimited 60
Integrated Ideas & Tech. 8
Jameco 55
Jaycar Electronics 11
LEDkit.biz 37
Lemos International Co., Inc. 9
Linx Technologies 24
LITEXPO 36
Lynxmotion, Inc. 24
Microchip 33
microEngineering Labs 85
Mouser Electronics 15
NetBurner 5
Net Media 2
PAiA 74
Parallax, Inc. .....Back Cover
PCB Pool 78
Pololu Robotics & Electronics 74
Pulsar, Inc. 36
QKITS 37
Rabbit, A Digi International Brand 3
Ramsey Electronics, Inc. 22-23
Renesas Technology Corp 25
Robo Development 75
Robot Power 73
Saleae LLC. 37
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[Module Comparison Chart]

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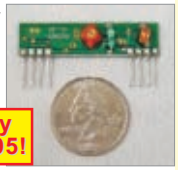

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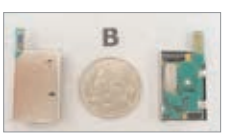

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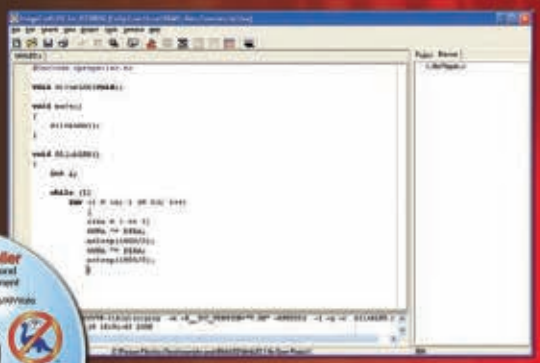

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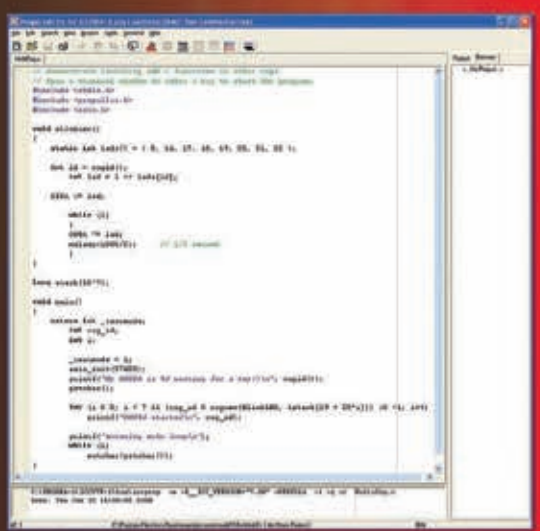

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